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GEOLOGY AND MINERAL RESOURCES OF THE MONTOURSVILLE SOUTH AND MUNCY QUADRANGLES AND PART OF THE HUGHESVILLE QUADRANGLE, LYCOMING, NORTHUMBERLAND, AND MONTOUR COUNTIES, PENNSYLVANIA

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by Rodger T. Faill
Pennsylvania Geological Survey

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PREFACE

The Williamsport area in Lycoming and surrounding counties in north-central Pennsylvania is one of the fastest growing urban and suburban areas in the state. The increasing demands for building materials, sites for urban expansion, and information on water resources and waste disposal require detailed information on the bedrock and surficial deposits. This part of the state has not been mapped geologically for nearly 100 years, so geological data are limited. This report is one of five geologic and groundwater atlases currently being produced to provide the detailed descriptions of the geologic bedrock, unconsolidated surficial deposits, and groundwater resources for this area. Also, the Williamsport vicinity displays the northernmost exposures of many rock units that are common to the south and southwest. Thus the geologic information here is relevant to an understanding of the geology of other parts of central Pennsylvania.

The report can be of benefit to a wide range of users. The sections on economic resources and environmental geology provide cogent information for decisions by local officials, county planners, industries, and land-use and highway planners. The descriptions of the rock units and geologic structures are important to design engineers and to the extractive industries, as well as to geologists who need data for specific site studies.

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(in envelope)

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Rodger T. Faill

ABSTRACT

The Montoursville South, Muncy, and Hughesville 7½-minute quadrangles lie in north-central Pennsylvania on the northern edge of the Valley and Ridge province of the Appalachian Mountains. Exposed sedimentary rocks are about 3000 m (9900 ft) thick, and in places are covered by up to 30 m (100 ft) of surficial deposits.

The exposed sedimentary rocks range in age from Upper Ordovician to Upper Devonian, and are divided into 15 formations. The Upper Ordovician and Lower Silurian quartzites (conglomeratic in part), sandstones, and shales are overlain by the sequence of shales, calcareous shales, and limestones belonging to the remainder of the Silurian. The Lower Devonian cherty limestones, sandstones, and shales are succeeded by marine shales and siltstones of the Middle and Upper Devonian. The surficial deposits comprise glacial till and drift, alluvium, and colluvium.

The Nittany anticline, and the White Deer syncline to the south, dominate the geologic structure. Smaller folds are present only in the northwest part of the mapped area. Faults, kink bands, cleavage, and planar veins are present, but not common. Distorted fossils indicate a flow deformation in addition to the flexural-slip kink-band folding. Fractures are parallel and perpendicular to the local fold axes, and are parallel to fracture orientations that are dominant in the Appalachian Plateau to the north.

Evaluation of the weathering character, slope stability, excavation difficulty, and foundation strength reveals marked contrast in these qualities among the different lithologies. Resource potential includes: limestone aggregate from the Upper Silurian rocks, including significant quantities of high-calcium ($CaCO_3 > 90$ percent) limestone; sand and gravel from alluvial deposits; glass sand; shale for clay products; tripoli; and shale for local fill.

INTRODUCTION

The Montoursville South, Muncy, and Hughesville quadrangles lie southeast of Williamsport at the northern edge of the Valley and Ridge province of the Appalachian Mountains in north-central Pennsylvania.

Williamsport, the main population center in this area (approximately 40,000), is a city of light to medium industry. Also encompassed within the mapped area are the smaller boroughs of Montoursville, South Williamsport, Muncy, and Montgomery. Surrounding areas are predominantly rural and are extensively farmed. Mountainous areas are heavily forested and not inhabited.

Previous geologic mapping in this area dates back to Sherwood and Platt (1880) of the Second Pennsylvania Survey. More recent work consists mostly of topical studies: stratigraphic (Colton, 1963; Oliver and others, 1969), surficial (Peltier, 1949; Denny and others, 1963; Bucek, 1975), and hydrologic (Lohman, 1939).

This report is a continuation of previous geologic mapping west of Williamsport (Faill and others, 1977a, b). A geologic report on the two quadrangles adjacent to the north (Montoursville North and Huntersville) is in press (Wells and Bucek). Supplementing these four reports is a report on the groundwater of the area (Lloyd and Carswell, in preparation). Mapping of the bedrock and surficial geology was conducted from June 1972 to September 1976.

PHYSIOGRAPHY

The mapped area can be divided into four topographic areas: the Susquehanna River valley, White Deer Valley, Muncy Hills, and Bald Eagle Mountain.

The Susquehanna River valley trends eastward across the northern part of the Montoursville South and Muncy quadrangles, and then trends southwestward to the southern boundary. It (along with Muncy Creek) consists of a floodplain up to 2 km (1.2 mi) wide that has one to two terrace levels, and adjacent low, rolling terrain. Surface drainage is dendritic and fairly well developed, particularly in the rolling terrain. The floodplain and terraces are exceedingly flat, and are ideally suited for agriculture, the principal current use. A number of factories and other buildings for light and medium industry have been established on the floodplain around Williamsport, where they are protected from flooding by levees. The two major rail lines lie on the terraces, as does the Williamsport-Lycoming County Airport. The adjacent low, rolling hills have been almost exclusively used for agriculture, but with recent growth, this terrain is increasingly used for light and medium industry and for residential purposes.

White Deer Valley (and Delaware Valley along the southern edge east of the Susquehanna River) is an extension of the low, rolling hills adjacent to the Susquehanna Valley. The topography has somewhat higher relief, and drainage is well developed and generally dendritic. West of Maple Hill is an area of coalesced sinkholes known as The Sink. Drainage is internal to this elongate sinkhole, which itself probably drains underground into Spring Creek to the west. The Sink overflowed during the Agnes storm in 1972, causing extensive local flooding that persisted for nearly a month. The White Deer and Delaware Valleys are extensively farmed and contain local stands of woods. In White Deer Valley, a large tract was converted to a munitions storage area during World War II. Since then, one half has been used as a federal prison farm, and the other half was given to the Commonwealth of Pennsylvania, which incorporated it into a State Game Land.

The Muncy Hills area begins with Penny Hill southwest of Montgomery, and widens eastwardly across the Muncy and Hughesville quadrangles and northward around Clarkstown and Hughesville. This terrain is very hilly and has considerably greater relief than the surrounding valleys. Drainage is dendritic and well developed, as evidenced by the numerous deep stream valleys throughout. Approximately one half of this area is utilized for agriculture, the remainder being forest land. Residential use is increasing, but is still of minor extent.

Bald Eagle Mountain crosses the central part of Montoursville South and ends at the Susquehanna River opposite Muncy. Possessing the highest relief of the four areas, it is rugged and mountainous. Drainage on its flanks is poorly developed and forms a trellis pattern. The one major stream in its center, Hagermans Run, is dendritic in pattern. A large gap through the mountain (southwest of Montoursville) may have been the site of a previous channel of the Susquehanna River because the present streams seem much too small to have created such a large gap. This area is completely forested and gets virtually no residential use; much of it is part of the Tiadaghton State Forest.

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Joseph Drahuschak (summer, 1973) and Joseph Fox (summer, 1974) materially aided the field mapping, particularly in the Muncy and Hughesville quadrangles. Additional assistance was given by Viktoras Skema and Bruce Hunter. William D. Sevon provided his valuable experience in sorting out the various surficial deposits.

STRATIGRAPHY

The rocks exposed in the Montoursville South, Muncy, and Hughesville quadrangles range in age from Upper Ordovician to Upper Devonian (approximately 450 to 365 million years old). This sequence is 3010 m (9875 ft) thick and is divided into 15 formations. The lithologies present include shale, siltstone, sandstone, limestone, and chert.

The coarse-grained rocks occur primarily in the Upper Ordovician Bald Eagle and Juniata Formations and the Lower Silurian Tuscarora Formation, and to a minor extent in the Lower Devonian Old Port Formation, which also includes chert. The limestones dominate the Silurian Mifflintown, Tonoloway, and Keyser Formations and the Devonian Onondaga Formation and Tully Member of the Mahantango Formation, and are present in the Silurian Wills Creek and Devonian Old Port Formations. The Silurian Rose Hill, Bloomsburg, and Wills Creek Formations, the Middle Devonian Marcellus and Mahantango Formations, and the Upper Devonian Harrell Formation are primarily shales, whereas the Upper Devonian Trimmers Rock Formation is interbedded shale and siltstone.

The origin of, and revisions to, the stratigraphic names are described in the report on the Millerstown quadrangle to the south, along with a sedimentologic interpretation of the deposition of each formation (Faill and Wells, 1974).

Surficial deposits of Quaternary age (1 million years ago to the present) overlie the bedrock throughout much of the mapped area. They range in thickness from 1 to 30 m (3 to 100 ft). The lithologies include alluvium (principally sand and gravel), glacial till, colluvium, and mixtures of these, in addition to other small surficial deposits.

ORDOVICIAN SYSTEM

The only Ordovician rocks exposed in these quadrangles are the two uppermost formations, the Bald Eagle and Juniata Formations. Together, they comprise 575 m (1885 ft).

Bald Eagle Formation

STRATIGRAPHY: As initially defined, the Bald Eagle Formation included the gray sandstones between the *Orthorhynchula* zone (Sowerbyella-Onniella community) in the Reedsville Formation and the red beds of the overlying Juniata Formation. Recent work (Thompson, 1970), however, has shown that these rocks were initially red, a color which was subsequently leached. As a consequence, the gray-red boundary occurs at different positions in different localities. Because of this, and because of the difficulty of mapping the color change underneath colluvium, the Bald Eagle was extended upwards to include the entire lower sandy interval of the Taconic clastic wedge. The position of the fairly abrupt decrease in grain size at the top of this interval is indicated by a break in slope that can be quite easily traced. In the Williamsport area, most of this lower sandy interval is gray.

LITHOLOGY: Very fine to coarse-grained quartzose sandstone (subgraywacke and graywacke), poorly to fairly well sorted. In the upper and lower portions, the sandstones are finer grained and have some interbeds of shale, shaly siltstone, and siltstone. A number of the sandstone beds in the medial portion are sparsely conglomeratic, containing predominantly well rounded quartz pebbles, 0.4 to 1 cm (0.2 to 0.4 in.) in diameter. This conglomeratic sequence is not prominent enough to map separately. It probably represents the northern feather edge of the conglomeratic Lost Run Member of the Bald Eagle to the south and southwest. Some of the sandstone beds also contain, near their bases, angular to subrounded, flat shale clasts, generally 2 to 5 cm (0.8 to 2.0 in.) long (maximum 15 cm, or 6 in.), or similarly shaped cavities from which shale clasts have been weathered out. Scattered small (2- to 4-mm) brown spots (limonite stains?) are common on fresh surfaces of many of the coarser sandstone beds.

COLOR: Medium light gray to medium gray and greenish gray in the lower and middle parts (weathering to light to medium gray, tan, or brownish gray); medium gray to grayish red in the upper portion (weathering to brown and grayish red). The shale beds and the clasts in the sandstones are red, green, or gray.

BEDDING: The sandstones are generally medium to thick bedded and are commonly crossbedded. The shale and siltstone beds are mostly very thin to medium bedded.

THICKNESS: 225 m (740 ft).

CONTACTS: The lower contact is not exposed. The upper contact is conformable and gradational, characterized by a marked increase of shale and siltstone beds and a decrease in grain size in the sandstones, over an interval of 5 to 10 m (16 to 33 ft).

BEST EXPOSURE: Along the road in Hagermans Run, and especially in the large quarry 1.4 km (0.9 mi) south of the Hagermans Run gap in Bald Eagle Mountain.

FIELD OCCURRENCE: Occurs in the mountainous terrain in and around Hagermans Run. Float is abundant, consisting of angular to subrounded boulders and cobbles of sandstone. Outcrops are not common, except in man-made cuts, as along the road through Hagermans Run, and in quarries. Underlies rolling, mountainous terrain.

Juniata Formation

STRATIGRAPHY: The Juniata Formation comprises the red sandstones, siltstones, and shales overlying the Bald Eagle Formation and underlying the white Tuscarora Formation. In this area it is informally divided into a lower fine-grained unit and an upper coarse-grained unit.

LITHOLOGY: Lower unit—siltstone and silty shale interbedded with very fine to fine-grained sandstone (graywacke and subgraywacke). Upper unit—fine- to medium-grained quartzite (50 percent), interbedded with very fine and fine-grained sandstone (subgraywacke and graywacke) (25 percent) and siltstone and shaly siltstone (25 percent). Some of the quartzite beds contain angular grayish-red shale pebbles up to 10 cm (4 in.) long.

COLOR: Medium grayish red.

BEDDING: Lower member—thin to very thick bedded. Upper member—the quartzites and sandstones are medium to thick bedded and extensively crossbedded; the siltstones are thin to medium bedded (occasionally thick bedded).

THICKNESS: 350 m (1150 ft). Lower member, 170 m (550 ft); upper member, 180 m (600 ft).

CONTACTS: Lower contact is conformable and gradational, represented by a marked increase of shale and siltstone beds and a decrease in grain size in the sandstone beds, over an interval of 5 to 10 m (15 to 30 ft). The upper contact is conformable and very sharp, consisting of a change from grayish-red subgraywacke in one bed to white quartzite in the overlying bed. The contact between the two members is placed where the sandstone beds become dominant. This increase in grain size is gradational, probably occurring over an interval of 5 to 10 m (15 to 30 ft).

BEST EXPOSURES: Lower member—intermittent outcrops along the road in Hagermans Run, 0.3 km (0.2 mi) south of the Hagermans Run gap in Bald Eagle Mountain. Upper member—along U. S. Route 15, 4.3 km (2.7 mi) east of South Williamsport.

FIELD OCCURRENCE: Occurs only in the western part of the mapped area, along the crest and south slope of Bald Eagle Mountain and near the crest and on the north slope of North White Deer Ridge. Float is common to abundant for the coarser sandstones, occurring mostly as cobbles and boulders (the finer beds are usually covered by the coarser material from higher on the mountain slopes). Outcrops are fairly common along the ridge crests, rare on the mountain slopes. Underlies high mountain ridges.

SILURIAN SYSTEM

The rock sequence of the Silurian System indicates that there was a decrease in the amount of coarse terrigenous material deposited in the Appalachian basin during this period. The quartzitic sandstones of the Tuscarora Formation are succeeded by the finer grained Rose Hill and Bloomsburg Formations. The Upper Silurian formations (Wills Creek, Tonoloway, and Keyser) are dominated by carbonates and contain only lesser amounts of terrigenous material.

The total thickness of the Silurian strata in the Muncy area is 1055 m (3460 ft).

Tuscarora Formation

STRATIGRAPHY: Throughout the Valley and Ridge province, the Tuscarora Formation consists predominantly of white quartzite, but in some areas, particularly in the northern part of the province, interbedded red and gray sandstones and siltstones of the Castanea Member occur above the main body of white quartzite and below the greenish-gray shales of the Rose Hill Formation. Because of its thinness and its resemblance to the underlying quartzites, the Castanea is usually included as a member of the Tuscarora Formation. It is present in these quadrangles, but is not mapped separately.

LITHOLOGY: Fine- to coarse-grained quartzite having interbeds of shale and siltstone (less than 30 percent), and occasionally coarsely laminated. The lower part is frequently coarse grained to conglomeratic, containing well-rounded quartz pebbles generally 2 to 5 mm in diameter, occasionally up to 10 mm. Castanea Member—an interbedded sequence of very fine to medium-grained siliceous sandstones and quartzites, siltstones, and shales.

COLOR: The quartzites are light gray, white, very pale green, and tan (weathering to white and light brown). The shales and siltstones are dark to medium gray, and dark greenish gray (weathering to light olive gray). Castanea Member—the quartzites are light gray and pale red, the sandstones grayish red and light gray, and the shales and siltstones olive gray.

BEDDING: The quartzites are medium to thick bedded, and extensively crossbedded; the finer grained rocks are generally very thin to thin bedded, occasionally medium bedded, laminated, and ripple marked. Castanea Member—the sandstones and quartzite are thin to thick bedded and crossbedded; the finer grained rocks are very thin to thin bedded.

THICKNESS: 75 m (250 ft) (Castanea Member included). Castanea Member—approximately 30 m (100 ft).

CONTACTS: Lower contact is conformable and very sharp, consisting of a change from grayish-red subgraywacke in one bed to white quartzite in the overlying bed. Upper contact is conformable and sharp, and is placed at the change from gray quartzite to olive-gray silty shale. The lower contact of the Castanea is also conformable and sharp.

BEST EXPOSURES: Along U. S. Route 15, 4.3 km (2.7 mi) east of South Williamsport. The Castanea is well exposed along Hagermans Run and along U. S. Route 15, 3.2 km (2 mi) east of South Williamsport.

FIELD OCCURRENCE: Occurs along the crest and/or northern slope of Bald Eagle Mountain, and along the crest and southern slope of North White Deer Ridge. Float is usually profuse, consisting of angular quartzite boulders. Outcrops are rare to absent on mountaintops and slopes, but fairly common on ridge crests and in gaps. Underlies high mountains.

Rose Hill Formation

LITHOLOGY: Slightly silty shale, poorly fissile, containing interbeds of: 1) siliceous siltstone; 2) calcareous siltstone, some containing lenses of abundant fossil material (mostly brachiopod debris) at the base, up to 5 m (16 ft) long, commonly 1 cm (2.5 in.) thick, maximum 5 cm (2 in.); 3) silty shale having fair to good fissility. The siltstones occur throughout the formation, but are particularly common (constituting as much as 30 percent of an interval) in the lower and upper parts of the formation. The shales that have good fissility are more common in the middle, in homogeneous intervals 2 to 10 m (7 to 33 ft) thick. Also in the middle is a 1-m- (3-ft-) thick crossbedded silty shale, poorly fissile; the crossbeds are at 15 to 20 degrees to bedding at the top and asymptotic at the base.

COLOR: Medium to medium dark gray, or greenish gray (weathers to light olive gray).

BEDDING: Generally very thick bedded, somewhat indistinct except where interbedded with siltstones. Lithologies 1) and 2) are very thin to thin bedded (some are laminated), commonly crossbedded, and flat to irregularly bedded; some have irregular scour bases, and ripples on top; rarely contain tracks. Lithology 3) is thick to very thick bedded.

THICKNESS: 290 m (950 ft).

CONTACTS: Lower contact is sharp and conformable, consisting of an abrupt change from gray quartzite to gray silty shale. Upper contact is gradational and conformable, consisting of an increase in limestone and a concomitant decrease in shale over a 5-m (16-ft) interval.

BEST EXPOSURES: The most complete exposure (90+ percent) is along U. S. Route 15, from 1 to 2 km (0.6 to 1.2 mi) south of Allenwood, which is

1.7 km (1.1 mi) south of the southern edge of the Montoursville South quadrangle.

FIELD OCCURRENCE: Occurs around the north, east, and south lower slopes of Bald Eagle Mountain, and the lower south slopes of North White Deer Ridge. Float, where present (unit is generally overlain by stony colluvium and recessional moraines), consists of light-olive-gray, flat, angular shale chips and pebbles. Outcrops are generally poor and sporadic, the better ones occurring in South Williamsport, along the east bank of the Susquehanna River north of Muncy, and in occasional borrow pits and roadcuts in White Deer Valley. Underlies moderate to moderately steep slopes along the foot of the mountains, moderately rolling terrain east of the Susquehanna River.

Mifflintown Formation

STRATIGRAPHY: Throughout much of the Valley and Ridge province south of Williamsport, the Rose Hill Formation is overlain by a clean calcareous or siliceous quartz sandstone called the Keefer Sandstone. Along U. S. Route 15 south of Allenwood, a 2- to 4-m- (7- to 13-ft-) thick, very fossiliferous (large brachiopods), calcareous sandstone and coarse-grained calcarenite overlies the Rose Hill and underlies the calcisiltites of the Mifflintown Formation. These coarse beds apparently represent the thinning northern edge of the Keefer Formation, because similar beds have not been found further north, although none of the exposures are as complete as the one south of Allenwood. Therefore, the Keefer Formation is considered to be absent in these quadrangles, and the Mifflintown directly overlies the Rose Hill.

LITHOLOGY: Interbedded limestone (80 to 35 percent) and calcareous shales (20 to 65 percent), fairly to poorly fissile and homogeneous, and fossiliferous in places. Among the limestones, laminated to homogeneous and, in places, fossiliferous and bioturbated, calcisiltites predominate, but also present in minor amounts are: 1) bioclastic calcarenite, containing brachiopod and crinoid fragments and intact fossils; 2) oncolitic calcisiltite, having oncolites approximately 2 to 3 cm (0.8 to 1.2 in.) in diameter; 3) pelletal calcarenite (medium-grained, in a silt matrix); and 4) oolitic calcisiltite.

COLOR: Medium to medium dark gray (weathering to light and medium light gray).

BEDDING: The limestones are very thin to medium bedded (rarely thick bedded), often parallel bedded, but some possess undulatory bedding surfaces. The shales are very thin to thin bedded.

THICKNESS: 60 m (200 ft).

CONTACTS: Lower contact is gradational and conformable, consisting of an upward increase in limestone and decrease in shale over a 5-m- (16-ft-) thick interval. The upper contact is not exposed. Incomplete exposures to the west along the north side of Bald Eagle Mountain suggest it is gradational and conformable, consisting of alternating red mudstone and gray limestone over an interval of approximately 5 m (16 ft).

BEST EXPOSURE: Along U. S. Route 15, 1 km (0.6 mi) south of Allenwood, which is 1.7 km (1.1 mi) south of the southern edge of the Montoursville South quadrangle.

FIELD OCCURRENCE: Occurs under the Susquehanna River in the north, along the lower south slopes of Bald Eagle Mountain and North White Deer Ridge, and in the western part of the Muncy Valley east of the Susquehanna River. Float is virtually absent, the unit being overlain by surficial deposits, except locally in Muncy Valley, where the float is rare, consisting of solution-rounded limestone cobbles and thoroughly weathered clay pebbles. Outcrops occur only rarely, in man-made cuts and excavations. Underlies gentle to moderate slopes.

Bloomsburg Formation

LITHOLOGY: Silty mudstone, having poor fissility and hackly fracture; homogeneous, calcareous in part. Some 1- to 2-m- (3- to 7-ft-) thick intervals of siltstone and silty, very fine grained, slightly calcareous sandstone. The lowest part, directly above the Mifflintown Formation, consists of algal beds interbedded with shale beds. The uppermost part contains interbeds of green to grayish-yellow-green, partly calcareous mudstone. The medial calcareous sequence of bryozoan calcisiltites, laminated calcisiltites, and bioclastic and oncolitic calcirudites, described west of the mapped area (Faill and others, 1977a) was not observed here and may not be present.

COLOR: Predominantly grayish red; has thin beds and patches of green to light olive gray in the upper portions.

BEDDING: The mudstones are medium to very thick bedded; the interbeds of siltstones and sandstones are thin to medium bedded.

THICKNESS: Approximately 175 m (575 ft).

CONTACTS: Lower contact is conformable and interbedded, consisting of alternating red mudstone and olive-gray algal beds over an interval of approximately 5 m (16 ft). The upper contact is conformable and interbedded over an interval of 10 m (33 ft), consisting of an interbedded sequence of partly calcareous, red and green mudstone beds.

BEST EXPOSURE: Exposures of the Bloomsburg Formation are few because this unit is overlain by thick alluvial deposits in the Susquehanna River valley and by till deposits in White Deer Valley. The best exposure occurs 3 km (1.9 mi) north of Muncy along Pa. Route 147.

FIELD OCCURRENCE: Occurs along the Susquehanna River valley and the northern part of White Deer Valley. Float is not common because of the overlying surficial deposits; where present, the float consists of small angular fragments. Outcrops occur mostly in man-made cuts and excavations. Underlies gentle to moderate slopes in rolling terrain where not overlain by surficial deposits.

Wills Creek Formation

LITHOLOGY: Interbedded sequence of mudstone, argillaceous siltstone, calcisiltite, and dolosiltite. The mudstones are silty, poorly fissile, and usually calcareous. The siltstones are calcareous, have occasional patches of sparry calcite, and are locally fossiliferous. A few siltstones are laminated and crossbedded, and siliceous. The calcisiltites are homogeneous to laminated. The dolosiltites are argillaceous and homogeneous, and laminated in places.

COLOR: The mudstones and siltstones are medium to medium light gray, weathering light olive gray to yellowish gray. In the lower part the siltstones are commonly variegated red and green, and have some interbeds of red mudstone. The calcisiltites and dolosiltites are medium to medium light gray, as are the siliceous siltstones.

BEDDING: The mudstones and siltstones are thin to medium bedded, and commonly laminated; the carbonates are laminated in part, and thin to medium bedded; the siliceous siltstones are laminated and crossbedded, and thin to medium bedded.

THICKNESS: 200 to 250 m (650 to 820 ft).

CONTACTS: The lower contact is conformable and interbedded over an interval of 10 m (33 ft). This interval consists of interbedded gray and red silty mudstones. The upper contact is not exposed, but is probably conformable and gradational. The upper part of the Wills Creek has a higher concentration of limestone beds and alternating 10- to 15-m- (33- to 50-ft-) thick intervals of predominantly shale or limestone. Thus, the upper contact is gradational with the overlying Tonoloway, perhaps over an interval as much as 60 m (200 ft).

BEST EXPOSURE: The Wills Creek Formation is very poorly exposed within the mapped area, because it is overlain by the thick alluvial deposits of the Susquehanna River valley and the glacial till of White Deer Valley. The best exposure is just east of Montoursville, behind an auto sales establishment south of U. S. Route 220.

FIELD OCCURRENCE: Occurs along the Susquehanna River valley and in White Deer Valley. Float is not common because of overlying surficial deposits; where present, it consists of small, angular fragments. Outcrops are rare, appearing usually in man-made cuts and excavations. Where not covered by surficial deposits, the formation underlies moderately rolling topography having gentle to moderate slopes.

Tonoloway Formation

LITHOLOGY: Predominantly calcisiltite, laminated, having cross laminations and algal-mat structures, separated by much thinner calcareous shale and argillaceous calcisiltite. The lower part contains a greater proportion of shale and argillaceous limestone. Ostracodes are common. The uppermost 5 m (16 ft) is predominantly a calcilutite that has extensive irregular patches of spar calcite (birdseye) and many stylolites parallel to bedding. This upper interval is more fully described in the "Economic Resources" section.

COLOR: Medium to medium dark gray, weathering medium light gray.

BEDDING: The calcisiltites are thin to medium bedded and platy; some are homogeneous, others laminated. The more argillaceous beds are very thin to thin bedded, and irregularly bedded. Clay and shale partings between the limestone beds are common.

THICKNESS: Approximately 175 to 225 m (575 to 740 ft).

CONTACTS: The lower contact is not exposed, but is probably conformable, consisting of interbedded shale and limestone similar to that in the upper part of the Wills Creek Formation. The upper contact is sharp and conformable, represented by an abrupt change from the thick- and very thick bedded calcilutites of the uppermost Tonoloway to the thick-bedded nodular limestone of the Keyser Formation.

BEST EXPOSURES: Extremely few within the mapped area except in a number of quarries. The best exposure is in the northwest end of the Lime Bluff quarry, 3.8 km (2.4 mi) northeast of Muncy.

FIELD OCCURRENCE: Occurs along the Susquehanna River valley and in White Deer Valley. Float is not common because of extensive overlying surficial deposits; where present, it consists of flat, platy cobbles, rounded by solution. Outcrops are rare, appearing usually in man-made cuts and excavations. Underlies gently rolling to flat topography (White Deer Valley) having gentle slopes and some sinkhole development.

SILURIAN-DEVONIAN TRANSITION

Carbonate sedimentation continued apparently without interruption from the Upper Silurian into the Lower Devonian. The presence of both Silurian and Devonian fossils in the Keyser Formation indicates that this stratigraphic unit spans the systemic time boundary.

Keyser Formation

LITHOLOGY: The lower part consists of nodular calcisiltite which possesses a distinctive cobbly weathering habit, minor thin interbeds of argillaceous calcisiltite, and a few discontinuous, thin chert layers. Stylolites parallel to bedding are common, as are clay partings between thick beds. A few beds of birdseye calcilutite are present, along with one bed of calcirudite containing rounded calcilutite fragments in a calcisiltite matrix. The upper part contains laminated, argillaceous calcisiltite and dolomites. Fossil layers, predominantly brachiopods, are scattered throughout the unit. A few calcarenite beds are also present. Barite (or celestite) is occasionally present in minor amounts.

COLOR: Medium light gray to medium dark gray; the cherts are black.

BEDDING: Lower part is medium to very thick bedded and contains very thin to thin beds of argillaceous calcisiltite and chert; upper part is thin to medium bedded, commonly laminated. Bedding surfaces are generally irregular to undulatory.

THICKNESS: 30 m (100 ft).

CONTACTS: The lower contact is sharp and conformable. The upper contact is similarly sharp and conformable, consisting of an abrupt change from laminated limestones and dolomites to the nonlaminated, thicker limestones of the Old Port Formation.

BEST EXPOSURES: The best and virtually complete exposure of the Keyser Formation occurs in the northwest end of the Lime Bluff quarry, 3.7 m (2.3 mi) northeast of Muncy.

FIELD OCCURRENCE: Occurs in the Susquehanna River valley and in White Deer Valley. Float is not common, because of overlying surficial deposits; where present, it consists of subangular small cobbles. Natural outcrops are rare; virtually all exposures occur in quarries and other man-made cuts. Underlies gentle to moderate, and locally steep, slopes on a low to moderate ridge.

DEVONIAN SYSTEM

The Lower Devonian Period marked the beginning of a fundamental change in the deposition in the Appalachian basin, a change from a nearly continuous carbonate deposition to a terrigenous sedimentation that was to persist with almost no carbonate interruptions (in central Pennsylvania) throughout the remainder of the Paleozoic. In the Old Port Formation, the limestones and cherty limestones common to the south and west are replaced in part by shale north of Muncy, and carbonate deposition ends with the Onondaga, except for the Tully limestone and siderite nodules, for the rest of the Devonian Period. The Middle Devonian black shales of the Marcellus gradually change up section to olive shales of the Mahantango. Calcareous shales appear at least twice in the Mahantango, before it terminates with an exceptionally thick Tully. The Upper Devonian rock units begin with the abrupt change to the Harrell black shales, which change into the sequence of alternating marine shales and siltstones characteristic of the Trimmers Rock Formation.

The total preserved thickness of the Devonian rock units in the mapped area is 1350 m (4430 ft).

Old Port Formation

LITHOLOGY: Predominantly limestone and shale containing subordinate amounts of sandstone and minor chert. The limestones are predominantly calcisiltites, which are mostly uniform but also mottled and cross laminated. Some of the calcisiltites contain irregular small patches and veins of white calcite, some of which are stained red with hematite. Birdseye calcilutites and medium- to very coarse grained calcarenites are also present in lesser amounts. The limestones are fossiliferous; crinoids and brachiopods are common, along with *Gypidula coeymanensis*. The calcarenites generally contain considerable fossil debris. The shales are generally uniform, rather fissile, generally calcareous, and contain brachiopods. The sandstones are medium grained, calcareous, well sorted, and friable, and large, heavy-shelled brachiopods are common. The chert occurs as isolated nodules in the lower part of the formation and as continuous beds in the middle portion. Pyrite occurs in association with calcite.

The relative portions of the lithologies vary within the three quadrangles. In the northern part of the Montoursville South quadrangle, at Lymehurst between Montoursville and Williamsport, the Old Port Formation consists of more than 50 percent sandstone. To the east, in the vicinity of Pennsdale, the sandstone is less than 10 percent, and gray and black shales make up more than one third of the unit. In White Deer Valley, two relatively thin sandstone intervals occur, one in the middle of the formation, the other at the top. At the western edge of the Montoursville South quadrangle in this valley, a 4-m- (13-ft-) thick red shale lies above the upper sandstone and below the gray shales of the Onondaga Formation. This red shale is not present at Montoursville. The generally poor exposure of this formation throughout the quadrangles precludes an estimate of the relative amounts of limestone and chert within the Old Port.

COLOR: The limestones are generally medium to medium dark gray; the shales are very dark gray to black; the sandstones are white to very light gray; and the cherts are black.

BEDDING: The limestones are thin to thick bedded, and have irregular to undulatory bedding surfaces. Internal laminations and crossbedding are not common. The shales are medium to very thick bedded, and have a fairly well developed fissility. The sandstones are medium to thick bedded and crossbedded. The cherts are thin to medium bedded.

THICKNESS: Approximately 150 m (490 ft).

CONTACTS: The lower contact is fairly sharp and conformable. The upper contact is very sharp and conformable, separating a coarse-grained sandstone from the overlying medium-dark-gray shale.

BEST EXPOSURE: Natural exposures of the Old Port Formation are rare and incomplete because of the widespread overlying surficial deposits. The best exposure of limestones occurs in the roadcut along Fairview Drive on the east side of Montoursville, north of U. S. Route 220. The best exposure of the sandstone is in a large quarry in the center of Lymehurst. The best exposure of the shale is north of Halls along U. S. Route 220 between Carpenters Run and Margaret Run. The red shale is exposed in a small borrow pit 150 m (500 ft) south of a farmhouse at the west edge of the mapped area, just north of the synclinal hinge.

FIELD OCCURRENCE: Occurs along the Susquehanna River valley and in White Deer Valley. Where present, float consists of angular weathered chert fragments, angular sandstone cobbles, and rounded limestone pebbles and cobbles. Outcrops are few, the best occurring in White Deer Valley west of Spring Creek along the western edge of the Montoursville South quadrangle. Underlies low to moderate ridge having gentle to moderate, and occasionally steep, slopes.

Onondaga Formation

LITHOLOGY: The Onondaga consists of a lower, predominantly shaly interval (Needmore Member) and an upper, predominantly limestone interval (Selinsgrove Member). In the Needmore Member, the lowest 3 m (10 ft) is a fissile, calcareous shale, overlain by 5 to 7 m (16 to 23 ft) of a noncalcareous, fissile shale. This grades upwards in the next 5 to 10 m (16 to 33 ft) into less fissile, calcareous shale which contains interbeds of argillaceous calcisiltite. These limestones occur as lenses in the lower part, and as well-defined beds in the upper part. This portion contains considerable disseminated pyrite crystals associated with calcite partings, in addition to scattered small brachiopods (*Orbiculoidea, Lingula*), also often associated with the pyrite. The Selinsgrove Member consists primarily of calcisiltites, ranging in internal structure from homogeneous to laminated to argillaceous. Some of the calcisiltites contain scattered, rounded pyrite blebs (0.5 to 7 mm) and are sparingly fossiliferous (for example, *Leptocoellina acutiplicata*). A few silty, very coarse grained pelletal(?) calcarenites, and very fine grained crossbedded bioclastic calcarenites are also present. The limestones are generally interbedded with calcareous fissile shales.

COLOR: The Needmore shales are medium dark to dark gray, grading up to medium dark gray in the calcareous portion; the limestones are medium gray. In the Selinsgrove Member, the limestones are medium dark to dark gray; the shales are medium dark gray.

BEDDING: Needmore Member—the shales are very thick bedded; the limestones are thin to medium bedded. Selinsgrove Member—the limestones are medium bedded (thin to thick bedded); the shales are very thin to medium bedded.

THICKNESS: 30 m (100 ft).

CONTACTS: Lower contact is sharp and conformable. Upper contact is gradational over 5 m (16 ft), consisting of a decrease in the number and thickness of limestone beds and a change in the shale from gray and calcareous to black and noncalcareous. The contact between the Needmore and Selinsgrove Members is gradational over approximately 5 m (16 ft), consisting of an upward increase of limestone from isolated lenses in the lower part to well-bedded limestone above, with a concomitant decrease in the amount of shale.

BEST EXPOSURES: The Needmore Member is best exposed in a quarry just east of Fairview Drive in the eastern part of Montoursville. The Selinsgrove Member and its gradational contact with the overlying Marcellus Formation is best exposed along the east bank of the Susquehanna River, 2.3 km (1.4 mi) southwest of Muncy, immediately south of the railroad bridge across the river.

FIELD OCCURRENCE: Occurs along the Susquehanna River valley and in White Deer Valley. Float is very rare because of widespread overlying surficial deposits; where present, it consists of solution-rounded limestone pebbles and cobbles. Natural outcrops are rare and poorly exposed. Underlies shallow valley or flat land having gentle and, in places, moderate slopes.

Marcellus Formation

LITHOLOGY: Homogeneous, carbonaceous, fissile, slightly silty shale, containing lenses and very thin beds of soft clay. Very widely spaced calcareous (siderite?) concretions 0.5 to 2 m (1.5 to 7 ft) in length occur in the lower part. Brown to dark-brown limonite films are found on many fractures and fissile partings. Few fossils are present, chiefly coelospiroid brachiopods (*Leiorhynchus limitare* Vanuxem).

COLOR: Dark gray to black, weathering to light gray; concretions are medium gray, weathering to light brownish gray.

BEDDING: Very thick bedded; very fissile to fissile to faintly laminated.

THICKNESS: In the vicinity of Montoursville, 105 m (345 ft); 135 m (440 ft) in the vicinity of Muncy; 150 m (490 ft) in the Delaware Valley along the southern edge of the mapped area.

CONTACTS: Lower contact is conformable and gradational over approximately 5 m (16 ft), characterized by a decrease in the limestones of the Onondaga and an increase in the noncalcareous black shales of the Marcellus. The upper contact is gradational over an interval of 10 to 15 m (30 to 50 ft) from a sooty black shale to a dark-gray shale.

BEST EXPOSURE: The best exposure is in a quarry east of Fairview Drive in eastern Montoursville, just north of the mapped area; two other extensive exposures occur in borrow pits north of U.S. Route 220, one in the farm along Tules Run 4.8 km (3.0 mi) east of Montoursville, the other on the west side of Twin Run 5.9 km (3.7 mi) east of Montoursville.

FIELD OCCURRENCE: Occurs along the Susquehanna River valley, and in White Deer Valley and Delaware Valley along the southern edge of the mapped area. Where the formation is not covered by surficial deposits, the float is rather common, consisting of flat, angular shale pebbles. Outcrops within the mapped area are sparse, occurring mostly in man-made cuts and excavations. Underlies moderately rolling terrain having moderate slopes.

Mahantango Formation

LITHOLOGY: Very slightly silty to silty shale, generally noncalcareous and poorly fissile. Two calcareous intervals are present, 130 m (425 ft) and 180 m (590 ft) below the Tully Member (which occupies the uppermost part of the formation). These intervals consist of calcareous silty shale and argillaceous calcisiltite, and occasional discontinuous layers of calcisiltite. They lithically resemble the more argillaceous part of the Tully Member and contain scattered trilobites. Above the 180-m (590-ft) calcareous interval is a sequence of noncalcareous shales that contain isolated siderite nodules (4 x 10 x 20 cm, or 1.6 x 3.9 x 7.9 in.). Similar nodules also occur in the upper 50 m (165 ft) of the Mahantango below the Tully. Larger concretions (0.5 x 1 x 1.5 m, or 1.6 x 3.3 x 4.9 ft) were found immediately south of U.S. Route 220, one-half way down the western valley side of Twin Run. In the lower part of the Mahantango the shales are more fissile and darker colored, reflecting the transition to the Marcellus below. The shales in the 30 m (100 ft) below the Tully also become quite fissile and slightly laminated. *Tully Member:* Calcisiltite and argillaceous calcisiltite. The lower half consists of interbedded argillaceous to nonargillaceous limestone beds, whereas the upper half consists almost entirely of argillaceous calcisiltites. Within the lower half (approximately one-fourth of the member thickness from the base), is a 5-m- (16-ft-) thick interval exhibiting large-scale crossbedding within very thick beds. Fossils are not common; those present are predominantly crinoid columnals and brachiopods.

COLOR: Generally medium dark gray to dark gray, weathering olive gray and light olive gray. Toward the base and near the top the color grades to very dark gray. The calcareous beds are medium to medium dark gray, weathering to light olive gray, yellowish gray, and medium light gray. *Tully Member:* Medium gray to medium light gray, weathering to light olive gray and yellowish gray.

BEDDING: Very thick bedded and homogeneous; thin to medium bedded in the calcareous intervals. *Tully Member:* In the upper half, very thin bedded, flat bedded, and parallel bedded; in the lower half, thin to thick bedded; in the crossbedded interval, crossbeds are 2 to 3 m (7 to 10 ft) high.

THICKNESS: The Mahantango Formation thins from west to east. At Montoursville it is approximately 515 m (1700 ft) thick, 75 m (250 ft) of which is in the Tully. In the vicinity of Muncy, the Mahantango is 425 m (1400 ft) thick and 60 m (200 ft) is in the Tully. Along the southern edge of the mapped area east of the Susquehanna the Mahantango is approximately 350 m (1150 ft) thick and 30 m (100 ft) is in the Tully. This southeastward thinning is compensated for in part by an increase in the thickness of the underlying Marcellus. Thus, the contact between the Marcellus and the Mahantango is rising up-section toward the southeast.

CONTACTS: Lower contact is very gradational and conformable. Upper contact is sharp and conformable, marking a change from argillaceous limestone to black shale over a 0.5-m (1.6-ft) interval. The basal contact of the Tully and the contacts of the calcareous intervals are sharp and conformable.

BEST EXPOSURE: The most complete and continuous exposure of the Mahantango occurs along the railroad tracks on the west side of the Susquehanna River 3 km (1.9 mi) south of Montgomery. An almost complete exposure of the Tully Member occurs along the south bank of Little Muncy Creek immediately south of Clarkstown. One of the calcareous intervals is well exposed along Pa. Route 147, 1.2 km (0.7 mi) north of the south edge of the mapped area.

FIELD OCCURRENCE: Occurs along the Susquehanna River Valley and underlies a large portion of White Deer Valley and Delaware Valley. Float is not common, because of overlying surficial deposits; where present, it consists of flat, angular pebbles of silty shale; float from the limestone in the Tully is rare. Natural outcrops are few; most exposures occur in man-made cuts and excavations. Underlies moderately rolling terrain having gentle to moderate, and in places steep, slopes.

Harrell Formation

LITHOLOGY: Homogeneous, slightly silty shale, very fissile; scattered very thin beds of laminated silty shale. Scattered siderite nodules occur in the upper 2 m (6.6 ft).

COLOR: Dark gray to black.

BEDDING: Very thick bedded, flat bedded.

THICKNESS: 45 to 60 m (150 to 200 ft).

CONTACTS: Lower contact is sharp and conformable. Upper contact is gradational over an interval of 2 m (7 ft).

BEST EXPOSURE: Along the south bank of Muncy Creek, immediately south of Clarkstown.

FIELD OCCURRENCE: Occurs along the northern edge of the Susquehanna River valley in the northern part of the mapped area and around the margins of the Muncy Hills in the southern part. Float is fairly common (where not covered by surficial deposits), consisting of small, flat, angular pebbles of black shale. Natural outcrops are not very common; most exposures occur in man-made cuts and excavations. Underlies gently to moderately rolling topography having gentle to moderate slopes.

Trimmers Rock Formation

STRATIGRAPHIC COMMENT: The name Trimmers Rock Formation is applied to the entire interval of Upper Devonian marine rocks between the Harrell Formation and the Catskill Formation. To the west and north (for example, Faill and others, 1977b) this interval is divisible into two stratigraphic units, the Brallier and Lock Haven Formations. These two formations differ significantly: the siltstones of the Brallier Formation are siliceous and fairly well sorted, whereas the siltstones of the Lock Haven Formation are argillaceous and frequently bioturbated; the shales of the Brallier Formation tend to be somewhat siliceous and very fissile, whereas the shales of the Lock Haven Formation are poorly fissile, bordering on mudstones; the fauna of the Brallier Formation tends to be made up predominantly of crinoids, and lesser numbers of bryozoans, brachiopods, and pelecypods, whereas the fauna of the Lock Haven Formation consists predominantly of brachiopods and lesser numbers of crinoids, fishplates, and ostracodes. In the Muncy Hills and to the east this lithic distinction is not present. Argillaceous siltstones characteristic of the Lock Haven Formation occur interbedded with shales and siltstones of Brallier affinity throughout the interval from the Harrell Formation to the Catskill Formation. Rather than extend the name Lock Haven downwards to the Harrell, or the name Brallier upwards to the Catskill, the name Trimmers Rock is brought northward from the lower Susquehanna Valley and applied to the entire Upper Devonian marine sequence in this area.

LITHOLOGY: Interbedded siltstone, shaly siltstone, and shale. The siltstones vary from siliceous and well sorted to argillaceous, poorly sorted, and locally very finely sandy. Some of the shales are siliceous and fissile, whereas others are soft, silty, and poorly fissile. A fauna of crinoids, bryozoans, and brachiopods is fairly common; a number of the siltstone beds are also bioturbated. Sole markings and ripple marks are also present in some of the siltstones. All of the beds are generally noncalcareous.

COLOR: The siltstones are medium gray to olive gray; the silty shales are medium to medium dark gray, weathering to olive gray and light gray; the shales are medium dark gray to olive gray.

BEDDING: The siltstones are thin to medium bedded, and thick bedded in places. Laminations and crossbedding are present in many of the siltstone beds. The shales and silty shales are generally very thin to thin bedded except in intervals lacking siltstone beds, where the shales are thick to very thick bedded.

THICKNESS: 560 m (1840 ft) in the mapped area.

CONTACTS: Lower contact is conformable and rather sharp, consisting of a change over 2 m (7 ft) from the black to dark-gray shales of the Harrell to the olive-gray noncalcareous shales of the Trimmers Rock.

BEST EXPOSURE: Along Pa. Route 147 through the Muncy Hills, from 2.6 km (1.6 mi) south of Muncy southward for a distance of 3.8 km (2.4 mi).

FIELD OCCURRENCE: The Trimmers Rock Formation occurs in the moderately high Muncy Hills, which extend from southwest of Montgomery eastward across the southern half of the mapped area to the eastern border, and northward east of Clarkstown and Hughesville. Outcrops are common along stream valleys and in roadcuts and other artificial excavations. Float is common (except on the steep hill slopes which are covered by colluvium) and abundant, consisting of subrounded to subangular pebbles and cobbles of siltstone and shale. Underlies moderate to high, rolling hills having moderate to steep slopes.

QUATERNARY SYSTEM

Pleistocene

Illinoian and Altonian Till, Undifferentiated

LITHOLOGY: Unsorted mixture of clay and silt, and pebbles, cobbles, and boulders. The clay fraction generally makes up 30 to 80 percent of the deposits. The pebbles, cobbles, and boulders are generally subrounded to rounded (some are subangular) and consist mostly of quartzite and sandstone. The sole significant exception to this is in the Delaware Valley south of the Muncy Hills, where the coarse fraction overwhelmingly consists of light-olive-gray, weathered siltstone clasts. Internal structures are nonexistent and the deposit generally has a very sticky consistency. The color ranges from bright yellow orange to reddish brown to yellow brown and in the Delaware Valley is generally light gray to pale yellow brown.

THICKNESS: The till has been mapped where it is one meter or more in thickness. The thickness ranges up to 45 meters (150 ft) (in northern White Deer Valley) but is more commonly 2 to 10 m (7 to 33 ft). Where till is present but less than 1 m (3 ft) thick it has been combined with other surficial units that are described in the following sections.

CONTACTS: Base of till deposits is generally in contact with bedrock or with stratified drift. Tills are usually overlapped or overlain by alluvial deposits and colluvium.

LANDFORMS: The topography on the till is generally flat to low rolling terrain having low relief, except where cut by streams or where it overlies particularly resistant bedrock ridges. Small, closed depressions are common where surface drainage is not well developed.

AREAL DISTRIBUTION: Till is common adjacent to the floodplain of the Susquehanna River valley, particularly along the northern edge of the mapped area and northeast of Montgomery. It is particularly well developed in White Deer Valley and is common in Delaware Valley along the south edge of the mapped area. It is present on the lower southern slopes of Bald Eagle Mountain, where it forms apparent recessional moraines. Till occurs only sporadically in the Muncy Hills.

EXPOSURES: The till is poorly exposed, except in man-made excavations and roadcuts. The best exposures are: along the east edge of the state game lands, 1.5 km (0.9 mi) south-southeast of Maple Hill in White Deer Valley; in the Allenwood prison camp 1 km (0.6 mi) west of the main administrative building; and in Montgomery, behind buildings along Pa. Route 54, opposite the railroad tracks.

ORIGIN: The till was deposited by ice sheets that moved over this area during the Illinoian and Altonian stages. The Illinoian till occurs primarily northeast of Montgomery, and in the White Deer and Delaware Valleys. The Altonian till occurs from Williamsport eastward and throughout Muncy Valley. The overwhelming presence of white and red quartzites, sandstones, and gray siltstone in the coarse fraction, and the absence of lithologies that are foreign to the bedrock of this area, suggest that most of the material was locally derived. This is supported by the gradational aspect between the till in White Deer Valley and the colluvium on the mountain slopes above the recessional moraines.

Recessional Moraine (on Plate 2, recessional moraine occurs with stony colluvium, undifferentiated; for description of stony colluvium see p. 30.)

LITHOLOGY: Unsorted mixture of clay, silt, pebbles, cobbles, and boulders; clay fraction makes up 30 to 80 percent of the deposit. The pebbles, cobbles, and boulders consist mostly of white, tan, and red quartzite and sandstone and are generally subrounded to rounded; some are subangular. Internal structures are nonexistent, and the deposits generally have a sticky consistency. Color ranges from yellow brown to reddish brown. This morainal material is indistinguishable lithically from till except for its landforms.

THICKNESS: Variable, from 2 to perhaps as much as 10 m (7 to 33 ft).

CONTACTS: Base of deposit is probably in contact with bedrock. It is generally overlain by a thin veneer of stony colluvium.

LANDFORMS: Recessional moraines are distinguished by linear ridges that trend obliquely to the slope contours within a terrain of rough, hummocky topography on the lower mountain slopes.

AREAL DISTRIBUTION: Recessional moraines have been identified only on the lower southern slopes of Bald Eagle Mountain.

EXPOSURES: Exposures are limited to a few shallow cuts along the power line that traverses and parallels the lower southern slopes of Bald Eagle Mountain.

ORIGIN: The moraines are depositional features formed during the intermittent eastward wasting of a glacier (probably Altonian) from White Deer Valley.

Till and Regolith, Mixed

GENERAL COMMENT: These surficial deposits encompass areas where both till and broken fragments from the underlying bedrock are present and often mixed together. The till deposit was either originally quite thin (less than 1 m (3 ft) thick) or has been almost entirely eroded away. In some places the till exists as a thin veneer above the regolith; elsewhere it has been mixed either by natural processes or by repeated plowing.

LITHOLOGY: This material has characteristics of both till and regolith (weathered bedrock and soil). The material generally consists of pebbles, cobbles, and, in places, boulders of white, tan, and red quartzite and of the underlying bedrock, in a matrix of clay or silty clay. The color is generally of low chroma, ranging from tan to yellow orange to pale brown. Internal structures are not present.

THICKNESS: These deposits are generally less than 2 m (7 ft) thick.

CONTACTS: Base of deposit is in contact with bedrock.

LANDFORMS: The topographic expression of areas underlain by till and regolith, mixed, are usually the higher parts of a rolling terrain and usually indicate to some degree the weathering resistance of the underlying bedrock unit.

AREAL DISTRIBUTION: These units occur throughout the mapped area, generally adjacent to till deposits. They are particularly well developed in the valley north of Muncy and in White Deer Valley.

EXPOSURES: Natural exposures are poor; observed man-made cuts are small and few.

ORIGIN: These deposits represent either the thin edges of till deposits or the erosional remnants of till.

Till and Colluvium, Undifferentiated

GENERAL COMMENT: In the Delaware Valley east of the Susquehanna River the coarser fraction of the glacial till consists primarily of light-olive-gray siltstone and shale cobbles and boulders and contains only small admixtures of quartzite. Where these deposits occur some distance from the Trimmers Rock outcrops in the Muncy Hills to the north, and particularly where a stream separates the deposit from its source, they have been mapped as glacial till. At the foot of the colluvium slopes, however, it is not always clear whether the deposits are an extension of the colluvium or are till. Therefore they have been mapped as till and colluvium, undifferentiated. Northeast and east of Clarkstown, this class of surficial material is also applied to similar small deposits, in which the coarse fraction is made up of both quartzites and siltstone fragments. These deposits are generally too thick or contain too much quartzite to be mapped simply as till and regolith, mixed.

LITHOLOGY: Generally an unsorted mixture of clay, silt, and minor amounts of sand, and coarse clasts (pebbles, cobbles, and boulders). The finer portion constitutes 50 to 80 percent of the deposit, and the coarse clasts consist of primarily siltstones and shales derived from the Trimmers Rock Formation and variable percentages of quartzite. The color generally ranges from pale yellowish brown to grayish brown. Internal structures are absent.

THICKNESS: Variable from 1 to more than 5 m (3 to 16 ft) thick.

CONTACTS: Base of deposit is generally in contact with bedrock.

AREAL DISTRIBUTION: Along the southern edge of the Muncy Hills from the Susquehanna River eastward through the Hughesville quadrangle, and in isolated patches east and northeast of Clarkstown.

EXPOSURES: Natural exposures are poor; shallow roadcuts exposed no more than 2 m (7 ft).

ORIGIN: Along the southern edge of the Muncy Hills, these deposits are a mixture of till derived primarily from the Trimmers Rock Formation immediately to the north, and colluviated rock from the steep slopes above.

Stratified Drift

LITHOLOGY: Predominantly well sorted, fine-grained sands, frequently exhibiting crossbedding and laminations. Near some of the margins of these deposits, the material grades laterally into a sandy gravel.

THICKNESS: Up to 15 m (50 ft).

CONTACTS: Basal contacts have not been observed. Overlain in places by till (probably Altonian).

LANDFORMS: Hills of low to moderate relief generally on the edge of major alluvial terraces or floodplains.

AREAL DISTRIBUTION: Only four significant deposits have been located within the mapped area. One is on north side of U. S. Route 220 between Twin Run and Turkey Run northwest of Halls; the second is east of Halls at Pa. Route 147; the third is north of Clarkstown on the southeast side of the Muncy Creek floodplain; and the fourth is west of Montoursville, on the west side of Loyalsock Creek just north of U. S. Route 220.

EXPOSURES: Natural exposures are poor; man-made exposures in both localities near Halls, and west of Montoursville, are covered with grass.

ORIGIN: The association of these deposits with glacial till and their stratification suggest that they were deposited by glacial meltwater in channels in or near the ice sheets.

Ice-Contact Stratified Drift

GENERAL COMMENT: Ice-contact stratified drift is distinguished from stratified drift because, despite their similar origin, their compositions differ greatly—the latter is fine grained, whereas the former is coarse grained and contains small inclusions of till.

LITHOLOGY: A mixture of sandy gravel and till. The gravel occurs in lenses of variable thickness within a medium-grained sand matrix (very little finer material) and also includes a moderate to large number of pebbles, cobbles, and even a few small boulders of quartzite and red and gray sandstone and siltstone. The till is very clayey, has a high-chroma reddish-brown color, and includes quartzite cobbles and some boulders. Deposits are moderately to highly variable laterally.

THICKNESS: At least 3 m (10 ft) thick, probably more.

CONTACTS: Basal contact not exposed. Deposits seem to be overlapped by alluvium and overlain by colluvium.

LANDFORMS: Hills of low relief within or at the edge of alluvial terraces and floodplains.

AREAL DISTRIBUTION: Three deposits of ice-contact stratified drift have been observed: one is in eastern South Williamsport, at the north end of the Little League playing fields; the other two are northeast of Muncy, surrounded by the alluvial terraces of Muncy Creek Valley.

EXPOSURES: Natural exposures are poor; good to excellent man-made exposures.

ORIGIN: The occurrence of both till and stratified beds in the same deposit indicates that they were formed in contact with or underneath the ice sheets.

Boulder Field

LITHOLOGY: Predominantly boulders of white quartzite; virtually no finer material between boulders, at least near the surface. Deposit consists of more than 50 percent quartzite clasts.

THICKNESS: 2 to as much as 15 m (7 to 50 ft).

CONTACTS: Base of deposit is not exposed; presumably it overlies bedrock. Lateral contacts are with boulder colluvium.

LANDFORM: Flat valley bottom in gap in Bald Eagle Mountain.

AREAL DISTRIBUTION: Only one boulder field was encountered in the mapped area, occurring in the gap in Bald Eagle Mountain where U. S. Route 15 passes through.

EXPOSURES: Upper surface is well exposed; no vertical exposures.

ORIGIN: Concentration of quartzite boulders from adjacent boulder colluvium, and subsequent washing away of finer interstitial material. No currently active movement. Presumably formed mainly during period of climatic severity associated with glaciation in the area.

Pleistocene to Recent

Alluvium

GENERAL COMMENT: The term "alluvium" comprises all the surficial materials exhibiting alluvial characteristics of good sorting, crossbedding, and channelling, and includes terraces and outwash deposits formed in association with the Illinoian and Altonian glaciations.

LITHOLOGY: Moderately to well-sorted deposits within the floodplains of the major streams, which exhibit crossbedding and channelling in fresh exposures. Median grain size varies from sand to gravel (see Economic Resources section for detailed analyses of the alluvium). The silt and sand grains are predominantly quartz, whereas the well-rounded granules and pebbles are predominantly red and gray siltstone and sandstone. These deposits frequently consist of interbedded sequences of gravel and sand beds, and there are abrupt changes in grain size vertically. Laterally, linear gravel bars can be traced for hundreds of meters. The sands generally occur in more widespread sheets. Alluvium along the smaller streams tends to have higher concentrations of silt and mud, along with gravel and cobble bars.

THICKNESS: Variable, generally more than 2 m (7 ft); commonly 5 to 15 m (16 to 50 ft); as much as 30 m (100 ft).

CONTACTS: Basal contacts not exposed; presumably the alluvium overlies bedrock or till.

LANDFORMS: Occurs in the flat terrains in floodplains adjacent to the major and lesser streams throughout the mapped area.

AREAL DISTRIBUTION: Predominantly in the floodplains along the Susquehanna River and Muncy Creek; to a minor extent along the lesser streams throughout the mapped area.

EXPOSURES: Natural exposures only in the upper 1 to 2 m (3 to 7 ft). Man-made exposures are rare, except in quarries and gravel pits.

ORIGIN: Deposited during and subsequent to Illinoian and Altonian glaciation; probably mainly Altonian; possibly mainly post-Altonian.

Alluvial Terrace

LITHOLOGY: Similar in all respects to alluvium; moderately to well-sorted silt, sand, and gravel deposits exhibiting crossbedding and channelling in fresh exposures.

THICKNESS: 5 to 30 m (16 to 100 ft).

CONTACTS: Basal contacts are not exposed; presumably the alluvial terrace deposits overlie bedrock, till, or stratified drift.

LANDFORMS: Large flat surfaces 2 to 5 m (7 to 16 ft) above the alluvial floodplains, located between the floodplains and the nonalluvial deposits on either side of the valleys.

AREAL DISTRIBUTION: Along the Susquehanna River and Muncy Creek only.

EXPOSURES: Fair to good. Best exposures are in borrow pits and quarries.

ORIGIN: Deposited by streams and rivers during and subsequent to the Illinoian and Altonian glaciation.

Stony Alluvium

GENERAL COMMENT: Stony alluvium is distinguished from alluvium by the admixture of a substantial proportion of locally derived cobbles and boulders.

LITHOLOGY: Variable deposits of mud, silt, and occasionally sand with an admixture of rounded cobbles and boulders that are locally derived. Sorting is generally poor and the size distribution tends to be bimodal, resulting from the high concentration of fine material and coarse clasts. The size and lithology of the clasts reflects the bedrock at the nearby source area. Thus, the stony alluvium in Hagermans Run consists of quartzite boulders and sand, whereas the stony alluvium in the Muncy Hills contains more mud and silt, and cobbles of siltstone.

THICKNESS: Variable; probably not more than 5 m (16 ft).

CONTACTS: Basal contact is with underlying bedrock; lateral contacts are generally with colluvium or till.

LANDFORMS: Narrow flat areas in the bottom of small valleys; sometimes has a hummocky, irregular surface.

AREAL DISTRIBUTION: These deposits occur in minor streams and in the headwater areas of the larger streams, as in the streams flowing off Bald Eagle Mountain and the Delaware Valley.

EXPOSURES: Generally fair to good, usually occurring in the banks of streams occupying the valley floors.

ORIGIN: Deposited by streams which erode colluvium from the steep adjacent valley sides. The coarser clasts are transported only during periods of high stream flow.

Alluvial Fan

LITHOLOGY: Mixed mud, silt, cobbles, and boulders having little internal structure. The cobbles and boulders consist primarily of red and white quartzite and sandstone. Proportion of coarser clasts is large, probably more than 40 percent of the deposit.

THICKNESS: Unknown, probably at least 10 m (30 ft).

CONTACTS: Basal contact is not exposed, but is probably on either bedrock or on alluvial deposits. Lateral contacts are with boulder and stony colluvium.

LANDFORMS: Fan-shaped in plan view, sloping upwards to an apex; downslope margin is convex.

AREAL DISTRIBUTION: Only one alluvial fan has been located in the mapped area: at the foot of the north slope of Bald Eagle Mountain just east of Sylvan Dell.

EXPOSURES: Poor.

ORIGIN: Probably accumulated during periods of high stream flow at the mouth of the mountain stream where it enters the Susquehanna River floodplain.

Alluvium and Colluvium, Undifferentiated

GENERAL COMMENT: Alluvium and colluvium, undifferentiated, has been mapped in areas having intermittent streams that exhibit some fluvial aspects, but in which an alluvial floodplain is not well developed.

LITHOLOGY: Variable; consisting primarily of mud, silt, occasionally sand, and a considerable number of cobbles and boulders of locally derived material. Internal structures are generally absent.

THICKNESS: Variable, from 1 to perhaps 5 m (3 to 16 ft).

CONTACTS: Basal contact not exposed, but presumably on bedrock. Lateral contact is with colluvium, till, or regolith.

LANDFORMS: Occupies shallow valleys in low to moderately high, rolling terrain. Floodplains grade imperceptibly into slopes on either side of stream.

AREAL DISTRIBUTION: In the valley north and south of Muncy, in White Deer Valley and Delaware Valley, and in the Muncy Hills.

EXPOSURES: Generally poor, except where dissected by the stream.

ORIGIN: Formed by either downslope creep or by stream action.

Colluvium

GENERAL COMMENT: The term colluvium includes all the surficial deposits consisting of disaggregated and chemically weathered bedrock that have moved downslope by creep or other gravity movement. In contrast, regolith consists of disaggregated and weathered bedrock that has remained largely in place.

LITHOLOGY: An unsorted mixture of clay, silt and pebbles, cobbles, and perhaps boulders having no internal structure. The composition of the coarse clasts reflects the bedrock upslope, from which the deposit was derived. The coarse clasts are generally angular to subrounded and constitute from 10 to 50 percent of the deposit. The largest clasts tend to be concentrated at or near the upper surface, but they may also extend throughout the deposit.

THICKNESS: Generally 1 m to as much as 5 m (3 to 16 ft).

CONTACTS: Basal contact is generally not exposed; presumably colluvium overlies bedrock. Upper lateral contact is placed where colluvium grades upslope into regolith.

LANDFORMS: Occupies steep to moderate slopes on low to moderate hills.

EXPOSURES: Natural exposures are poor; best man-made exposures occur along roads.

ORIGIN: Developed by downslope movement of disaggregated and weathered bedrock.

Stony Colluvium

LITHOLOGY: A variable mixture of clay, minor amounts of silt and sand, and abundant pebbles, cobbles, and boulders. Clay constitutes from 20 to 50 percent of the deposit; the coarser clasts make up the remainder The coarse clasts are predominantly white and gray quartzitic sandstones and there are lesser amounts of red sandstones. Sorting and internal structures are absent. The larger cobbles and boulders are concentrated at or near the upper surface of the deposits. The color is commonly yellowish brown.

THICKNESS: From 1 to 10 m (3 to 33 ft).

CONTACTS: Base of deposit is in contact with bedrock; upslope latera contact is with boulder colluvium.

LANDFORMS: Moderate slopes at the foot of Bald Eagle Mountain. The surface is irregular and hummocky and covered with boulders. Shallow stream channels and debris flows are common on the surface.

AREAL DISTRIBUTION: Along the north slope of Bald Eagle Mountain between South Williamsport and Sylvan Dell, and along the southern slopes of North White Deer Ridge and Bald Eagle Mountain.

EXPOSURES: Natural exposures are poor to absent. A few man-made exposures occur along U. S. Route 15. A particularly good exposure is east of South Williamsport, just south of U. S. Route 15 behind the Hill's Shopping Center, where 10 m (33 ft) of stony colluvium is exposed above bedrock.

ORIGIN: Developed by downslope gravity movement, particularly during periods of severe climate associated with glaciation in the area.

Boulder Colluvium

LITHOLOGY: A variable mixture of clay, cobbles, boulders, and minor amounts of silt, sand, and pebbles. No internal structure, except that boulders, which constitute from 40 to 70 percent of the deposit, are concentrated near the upper surface. Finer material is generally absent in the upper 1/2 m (1.6 ft), giving the deposit a very rough, irregular surface. The coarse clasts are predominantly white quartzite boulders from the Tuscarora Formation, except in Hagermans Valley, where the boulders consist of siliceous gray graywacke and red sandstone.

COLOR: Varies from yellowish gray to brown to reddish brown.

THICKNESS: Variable, at least 2 m (7 ft) and perhaps as much as 5 m (16 ft) thick.

CONTACTS: Base of deposit is in contact with bedrock; upslope lateral contact is with regolith at top of slopes. Downslope lateral contact is with stony colluvium on lower slopes of the mountain.

LANDFORMS: Steep to moderate slopes, highly irregular and extremely hummocky; very few surface drainage channels.

AREAL DISTRIBUTION: Along the steep slopes of Bald Eagle Mountain and North White Deer Ridge.

EXPOSURES: Poor to absent.

ORIGIN: Developed by downslope gravity movement, particularly under periglacial conditions.

Shale-Chip Rubble

LITHOLOGY: A completely disaggregated deposit of subrounded shale fragments of sand to granule size. Small subrounded pebbles and cobbles of siltstone are occasionally present, constituting less than 5 percent of the deposit. Internal structures comprise a coarse stratification which is commonly deformed into folds and faults as a result of downslope creep.

COLOR: Medium brown to light brown to olive gray.

THICKNESS: From 2 to more than 10 m thick (7 to 33 ft).

CONTACTS: Base of deposit is not exposed; presumably it overlies bedrock. Lateral contacts are with colluvium.

LANDFORMS: Occupies steep west-facing slopes having fairly smooth surface.

AREAL DISTRIBUTION: Only five deposits have been located in the mapped area, all of them in borrow pits in the Trimmers Rock Formation. Two are east of Hughesville, two are east and north of Clarkstown, and one small deposit occurs along the west side of Warrior Run. Many other similar deposits may occur in the Muncy Hills and east of Hughesville, but only excavation will confirm their presence. They are difficult to locate because their surface expression is very similar to that of ordinary colluvium.

EXPOSURES: Excellent in man-made exposures in borrow pits.

ORIGIN: Developed by disaggregation of the finer shales in the Trimmers Rock Formation, followed by downslope movement either by creep, sheetwash, or solifluction processes.

STRUCTURAL GEOLOGY

INTRODUCTION

The Montoursville South, Muncy, and Hughesville quadrangles lie entirely within the Valley and Ridge province of the Folded Appalachians. The two structures that dominate this mapped area are the Nittany anticline and the White Deer syncline, both first-order folds (wavelength greater than 10 km, or 6 mi). Although second-order folds (wavelength from 1 to 10 km, or 0.6 to 6 mi) appear to be absent, smaller, third-order folds (wavelength from 50 m to 1 km, or 164 ft to 0.6 mi) occur in the vicinity of Lymehurst, and fourth-order structures (wavelength from 50 cm to 50 m, or 20 in. to 164 ft) are exposed in Hagermans Run and along Muncy Creek north of Muncy. Only one fault of any consequence (the Williamsport fault) is present, in the vicinity of Lymehurst, and is probably associated with the folds there.

Other structures, such as kink bands, minor faults, slickensides, cleavage, and distorted fossils occur in some outcrops. Fractures—planar (joints), curved, and irregular—are present in virtually every outcrop.

Exposures in the Montoursville-Muncy area are generally poor so that fold geometry must be inferred. However, the presence of both large and small kink-band structures in adjacent quadrangles (Faill and others, 1977a, 1977b) and the occurrence in this report area of kink-band geometry in a few outcrops leads to the inference that the larger folds approximate a kink-band geometry as well.

FOLDS

The Nittany anticline and White Deer syncline cross the three quadrangles in an approximately east-west direction. Despite a few small areas of unusual bed attitudes, the absence of second- and third-order folds and faults of any significance (except around Lymehurst) give the area a structural simplicity unusual for the Valley and Ridge province. Although the extensive surficial deposits could be masking smaller structures in anticlinal limbs, map-pattern widths are generally consistent with the formational thicknesses and dips of bedding extrapolated from the nearest outcrops. As with most other folds in the province, bed attitude is constant across the fold limbs, the hinges are very to moderately narrow relative to the fold wavelength, and bed thicknesses do not change appreciably throughout the folds (Figure 1). These are attributes of kind-band folds (Faill, 1973).

Despite the constancy of bed dip across the limbs, the bedding dip decreases markedly from west to east, particularly in the north limb of the Nittany anticline. The dips there decrease from vertical (and even overturned) at South Williamsport to moderately steep (40 to 60 degrees) at Sylvan Dell, to gentle eastward from Muncy. The bedding in the anticlinal south limb decreases from moderate (20 to 45 degrees) around Montgomery to gentle (0 to 15 degrees) east of Muncy. This decrease in both limbs reflects both the east plunge of the Nittany anticline and the lessening of its amplitude. The White Deer syncline has its north limb in common with the south limb of the Nittany anticline, and thus the dips there decrease eastwardly. In the south limb, however, the dips are uniformly gentle across the mapped area. As a result, the synclinal plunge to the east is less than that of the Nittany anticline, an average of 2 degrees as opposed to 6 degrees respectively. The apparent structural relief on the west edge of the mapped area is 1965 m (6450 ft), whereas on the eastern edge it has decreased to a mere 50 m (165 ft).

Further to the east, no dip reversal exists to indicate the presence of these two major folds—the beds dip homoclinally to the north. Thus, the Nittany

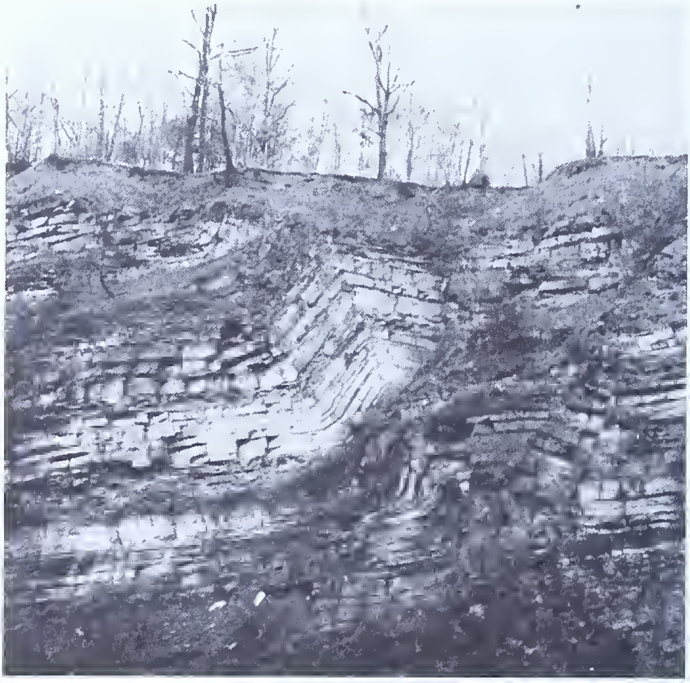


Figure 1. Small kink-band fold in the Brallier Formation in an inactive quarry just north of Williamsport. The narrow hinge, constant bed attitude within each limb, and constant bed thicknesses across the fold are the definitive characteristics of kink-band folds.

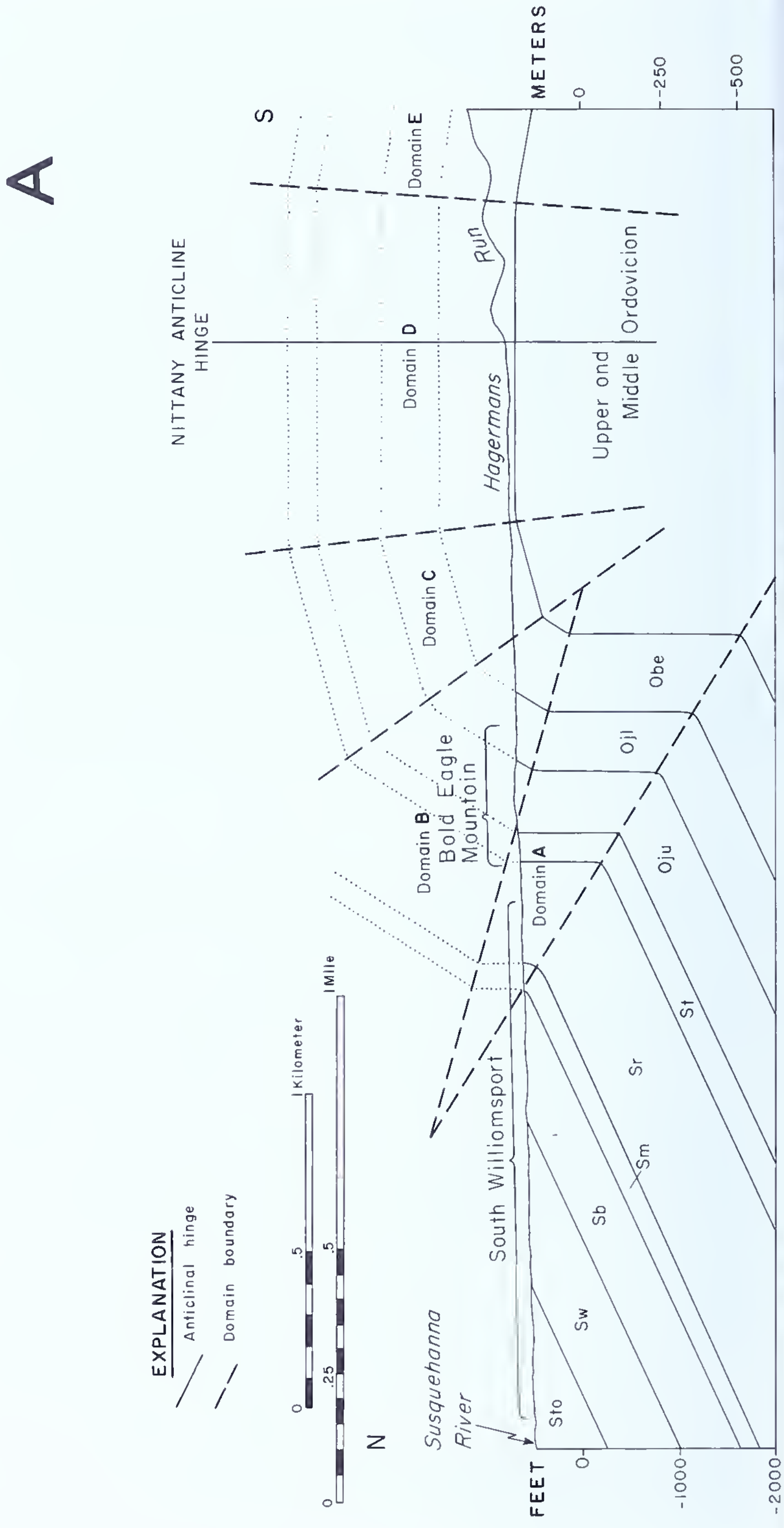
anticline and the accompanying White Deer syncline, large first-order folds in the western part of the mapped area, decrease in fold amplitude to zero over a distance of 28 km (17.4 mi) (compare cross sections A-A′, B-B′ and C–C′). The termination of these two folds marks the eastward limit of the Valley and Ridge structural province in this area, replaced by the Allegheny Plateau type of structure to the east. The northern limit of the Valley and Ridge province shifts southward to the next first-order fold.

The axial traces of these two folds are approximately parallel across the mapped area and thus the fold half-wavelength (measured as the distance between the two axial traces) does not change greatly along the length of the folds (6.5 km, or 4.1 mi in the west versus 5.0 km, or 3.1 mi), despite the large decrease in fold amplitude. But the change in the folds is not constant—both the trend of the axial trace and the plunge vary along their lengths. In the west, in the Hagermans Run area, the Nittany anticline trends 072, plunging to the northeast at 7 degrees. Eastward, where the Tuscarora caps Bald Eagle Mountain, the trend is 091 and the plunge is eastward at 1.5 degrees. From the Susquehanna River eastward, the fold trends 080, plunging 10 degrees. In contrast, although the White Deer syncline axial trace roughly parallels that of the Nittany anticline (058 in the west, 082 through the Muncy Hills, and 064 at the eastern edge), the steepest plunge is in the west (5 degrees) and the shallowest in the east (1/4 degree).

In cross section, both folds exhibit profiles characteristic of kink-band folds, particularly the White Deer syncline. Along its entire length, the hinge is narrow, the limbs are broad, and the dip is relatively constant throughout. The Nittany anticline is not as simple. In Hagermans Run, the fold is conjugate, and the beds in the south limb dip southeast at approximately 20 to 25 degrees. The hinge consists of a zone 0.9 km (0.6 mi) wide in which the bedding dips uniformly down the fold plunge. The north limb is more complex (Figure 2a), comprising four domains which are, from the north: one domain, covered by surficial deposits, presumed to possess moderately north dipping beds; domain A, which has vertical beds; domain B, which possesses moderately steep, north-dipping beds; and domain C, which has gently dipping beds. As shown in the stereogram (Figure 2b), bedding attitude does not change smoothly from subhorizontal to vertical—bed dips are quite constant within each domain, and change abruptly across the narrow domain boundaries.

To the east, in the gap south of Sylvan Dell, the change in attitude seems to be spread over a zone 1.8 km (1.1 mi) wide, similar to that of a concentric fold. But even this width is small compared to the wavelength of the entire fold (12+ km, or 7.5+ mi). However, it is east of the Susquehanna River where the Nittany anticline is least similar to a typical kink-band fold.

North and northeast of Muncy, the hinge is approximately 3.6 km (2.2 mi) wide. But the change in attitude across the hinge is not smooth. Rather, the hinge appears to consist of a number of domains (Figure 3a), within each of which the bed attitude is constant and intermediate in strike and dip between those of the adjacent zones or limbs (Figure 3b). Grossly, the hinge profile is concentric, but in detail it consists of a number of straight-line (rectilinear) segments, as diagrammed in Figure 3c. The paucity of bedding data in this area makes support of this rectilinear interpretation difficult, but the domain structure (areas of constant bed attitude, and abrupt changes from one domain to another) is present. In Figure 3a, three domains (A, B, and C) have been drawn, and all the bedding readings (except those on the hinge) have been plotted and identified on the stereogram (Figure 3b). Three well-defined clusters stand out; there are 12 to 15 spherical degrees between the cluster means, and only small dispersion within the clusters. No bed reading from one domain falls within the cluster of another domain. The two north-dipping attitudes at Lime Bluff indicate that another trend is crossing, and is contained within, domain A. The hinge widens to the east past Hughesville, still consisting of domains of constant attitude. With the widening of the hinge, the fold amplitude decreases to the point (at the east margin of the mapped area) where the beds between the axial traces no longer dip southward, but to the east. The anticline-syn-


A
S
N
NITTANY ANTICLINE HINGE
Domain E
Domain D
Domain C
Domain B
Domain A
Bald Eagle Mountain
South Williamsport
Susquehanna River
Hagermans Run
Upper and Middle Ordovician
Obe
Ojl
Oju
St
Sr
Sm
Sb
Sw
Sto
METERS
0
-250
-500
FEET
0
-1000
-2000
EXPLANATION
Anticlinal hinge
Domain boundary
0 .5 1 Kilometer
0 .25 .5 1 Mile

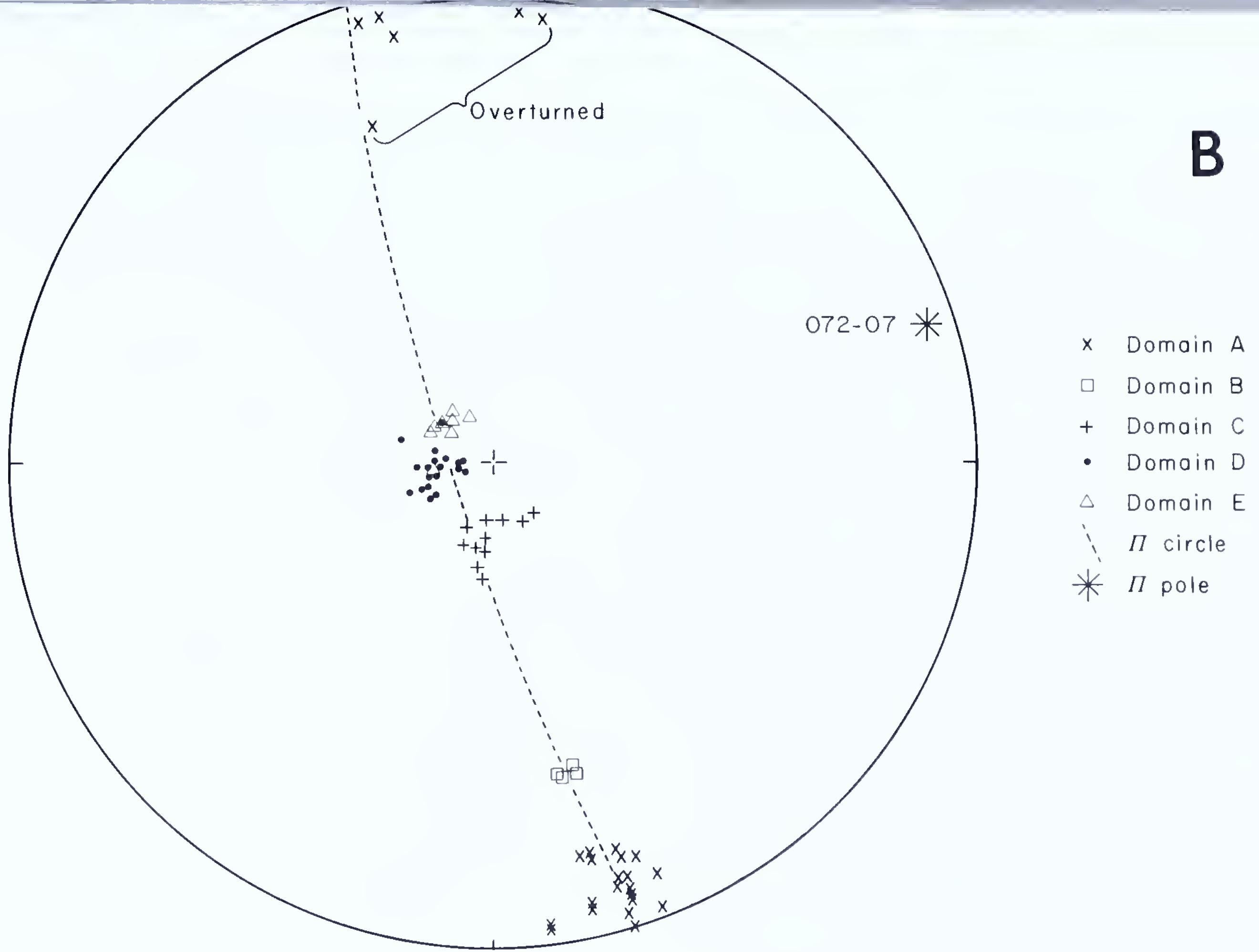


Figure 2. Hinge and north limb of the Nittany anticline at Hagermans Run. A. Cross section showing kink domains in the north limb and the rather broad hinge of east-dipping beds. B. Stereogram showing clustering of bedding poles within each domain.

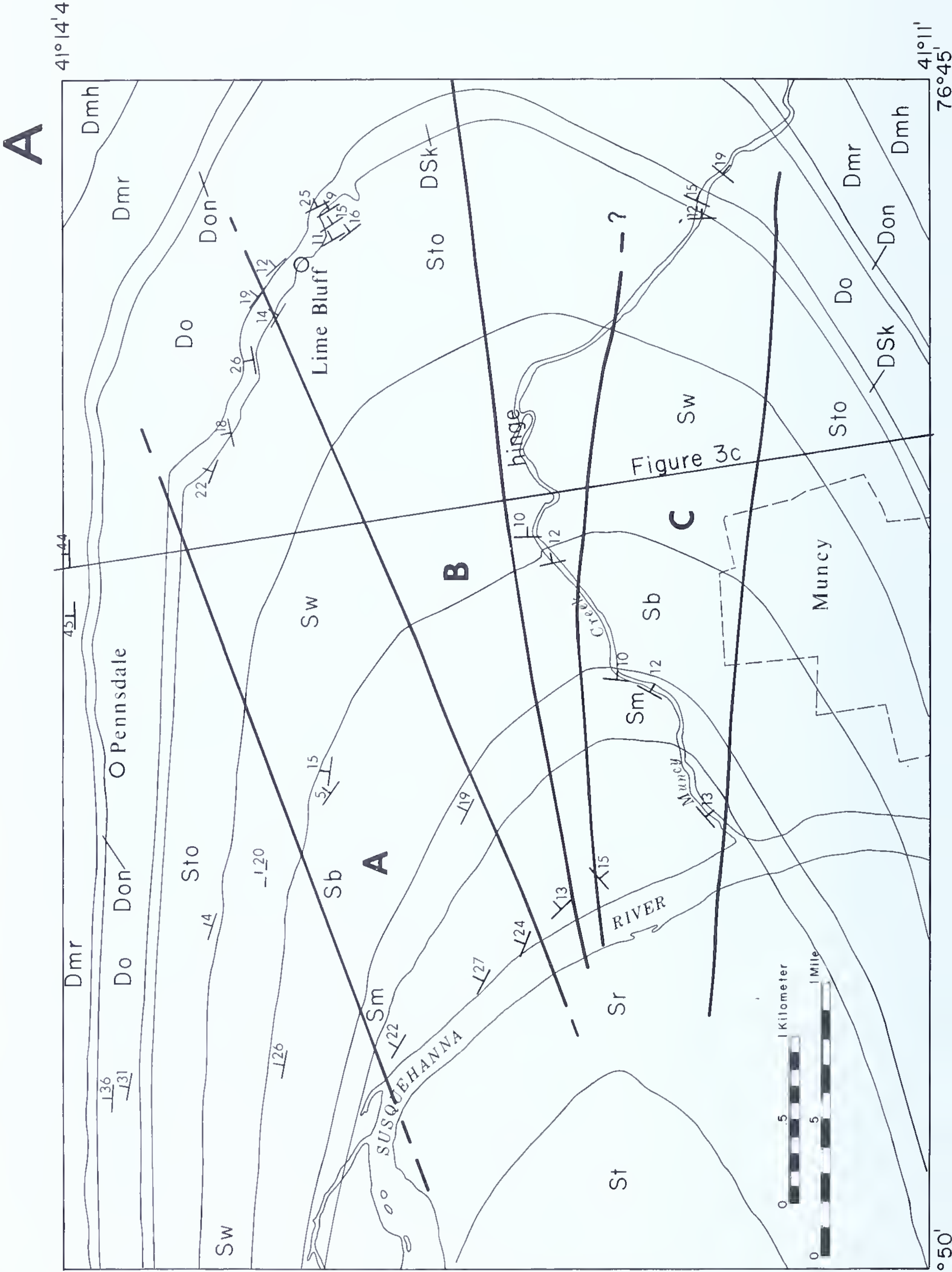
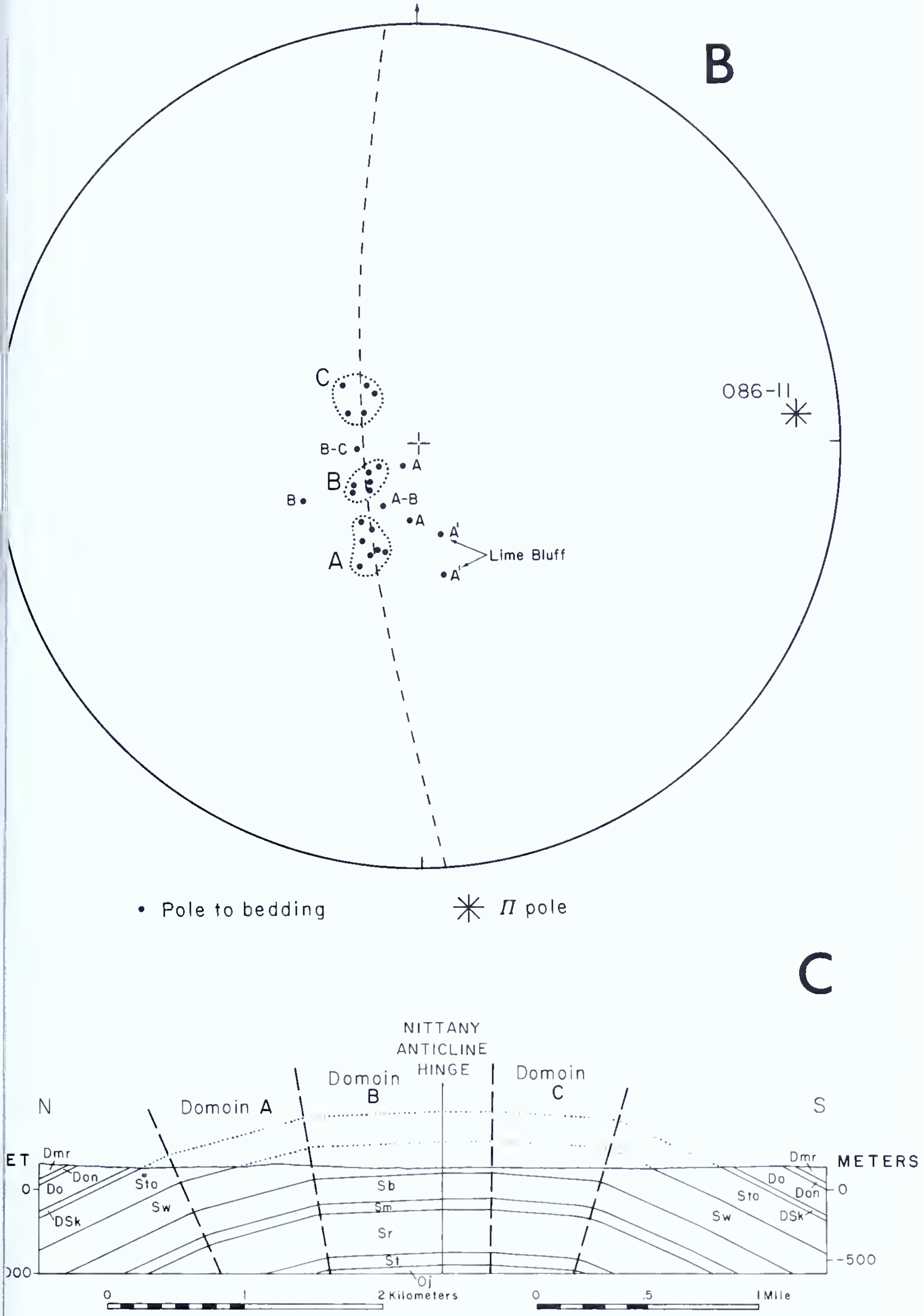


Figure 3. Rectilinear domains of the Nittany anticline north of Muncy. A. Geologic map (reduced from Plate 1) showing boundaries of domains. B. Stereogram showing clustering of bedding attitudes. Throughout each domain, bed attitude remains largely within the



cluster. The shift in attitude from one cluster (domain) to the next occurs over a very short distance, constituting the domain boundary (e.g., bed pole A-B, or B-C). C. Cross section illustrating the rectilinear nature of the fold.

cline pair thus becomes a structural terrace within the homocline that consists of the north-dipping beds of the anticline's north limb and the syncline's south limb. Further east, the direction of the dip of bedding in the terrace changes from east to northeast and then north. At this point all trace of the Nittany anticline and White Deer syncline vanishes into the uniform homocline of north-dipping beds.

As mentioned above, the trend of the Nittany anticline and White Deer syncline is approximately east-west throughout much of the area. In the Nittany anticline, it is only in the western portion, primarily in the vicinity of Hagermans Run, that the structural trend is to the northeast and that the beds in the north limb are the steepest. Slickenlines* on bedding are indicators of the direction of slip between beds during folding. In Figure 4, the slickenlines from the vicinity of Hagermans Run and immediately to the north (western domain) define a trend of 068, very close to that of the Nittany axial trace in that area. In contrast, the slickenlines from all the rest of the mapped area, from Lymehurst and White Deer Valley eastward (eastern domain), define an east-west trend. Thus, the slickenlines indicate that a major trend change occurs just east of Hagermans Run, separating the northeast trend, which is characteristic of the Nittany anticline over much of its length from Tyrone (115 km (70 mi) to the southwest) to Williamsport, from the east-west trend, which predominates as the fold dies out to the east.

MINOR FOLDS

Folds smaller than the Nittany and White Deer structures are not common in these quadrangles. Third- and fourth-order folds are present in the Lymehurst area, and some gentle folds occur in a small area in White Deer Valley just south of the mapped area. Third-order folds are probably present under the Susquehanna River floodplain south of Montoursville (inferred from fresh red shale and limestone fragments brought up during sand and gravel dredging close to Bald Eagle Mountain). A fourth-order gentle fold (or terrace) appears to exist in the south limb of the White Deer syncline in Warrior Run just east of the cross-section B–B′ line. A third-order kink band is inferred in the White Deer syncline (north limb, cross-section A–A′) because all the Silurian formations cannot be fitted in at a constant 20- to 25-degree dip without thinning these stratigraphic units. The remainder of the quadrangles is apparently devoid of such minor structures

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*Slickenline is a term recently introduced by Fleuty (1975) to distinguish between slickensides and the striations on the slickensides. A slickenside is a surface (bedding, fracture, cleavage, etc.) along which movement has occurred, and on which striations (slickenlines) have been formed.

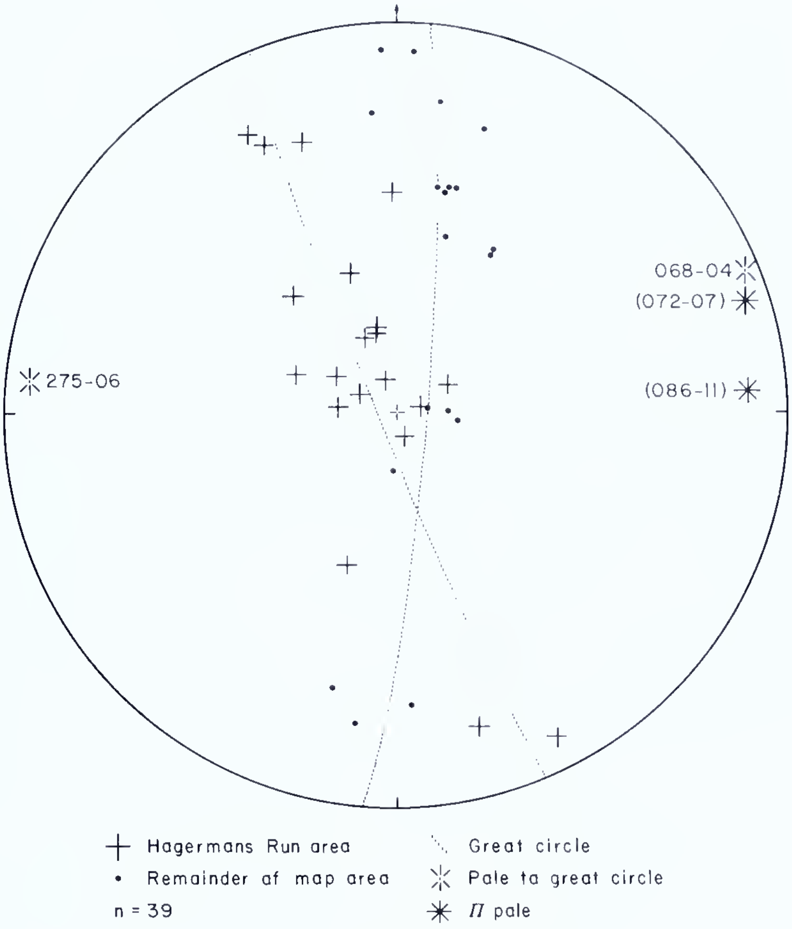

Figure 4. Summary of all slickenlines on bedding surfaces throughout the three quadrangles. Two trends are readily discernible. A northwest-southeast girdle is developed from measurements in Hagermans Run only. Slickenlines from elsewhere in the mapped area define a north-south girdle, reflecting a major change in tectonic trend just east of Hagermans Run.

except for kink bands in Hagermans Run and along Muncy Creek, which are discussed in the following section.

The carbonate hill in the Lymehurst area is a third-order, west-northwest-trending anticline that has a number of fourth-order folds superimposed in its limbs and hinge. Fold axes, derived from bedding measurements across exposed hinges, plunge west-northwest (Figure 5), parallel to the trend of the third-order axial trace. Although in general these folds are not well exposed, they do exhibit two characteristics of kink-band folds—a divergent (from the regional) trend and two directions of slickenlines on bedding surfaces.

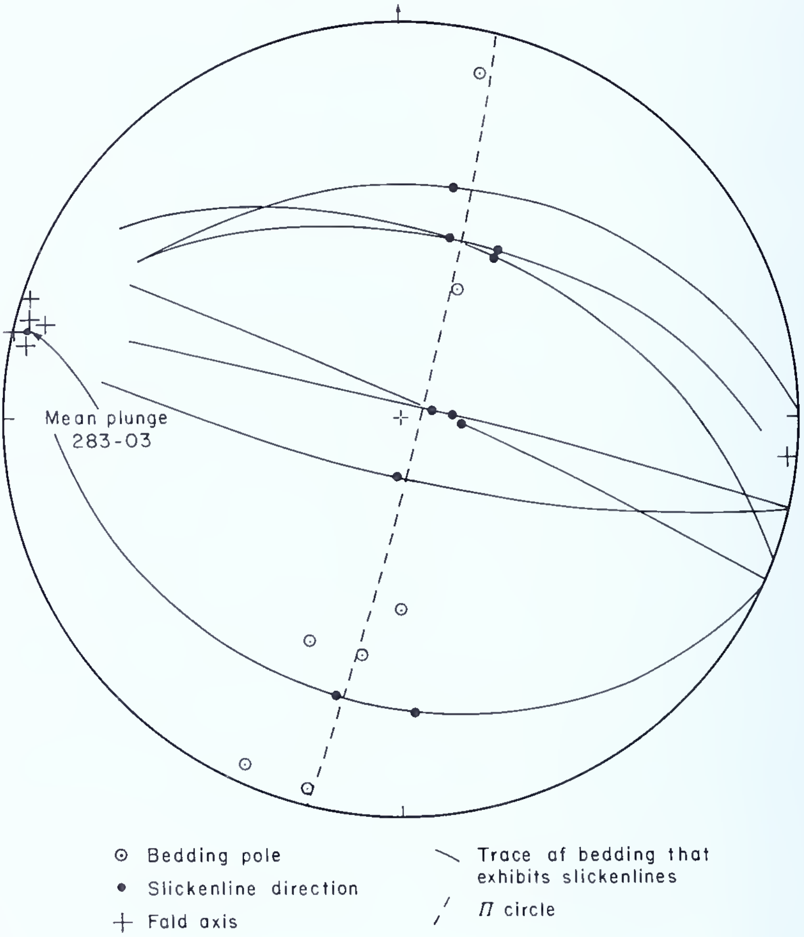

Figure 5. Fold axes of fourth-order folds in the Lymehurst area. Th west-northwest plunge parallels the local structural grain a indicated by the west-northwest trend of the axial traces of th third-order folds on the map. Slickenlines on bedding surface define a girdle perpendicular to the fold axes. Mean plunge i 283-03.

Near the west end of Lymehurst, in the rock face just east of the Loyalsock Township building, a fold, since removed for parking lot expansion was broad and open in the upper level, but changed into a kink band belo in the lower part. The fold axis defined by the bedding poles in the uppe portion plunged 1 degree east, whereas the fold axis in the lower par plunged 3 degrees west-northwest (Figure 6). It is unusual for two differen parts of a fold at a single locality or outcrop to possess divergent trends, bu interfingering of trends near areas of changing structural grain is common.

Near the eastern end of the Lymehurst hill is an abandoned quarry exposing subhorizontal beds in the southern part, and subvertical to overturned beds in the northern part. Two directions of slickenlines, divergin

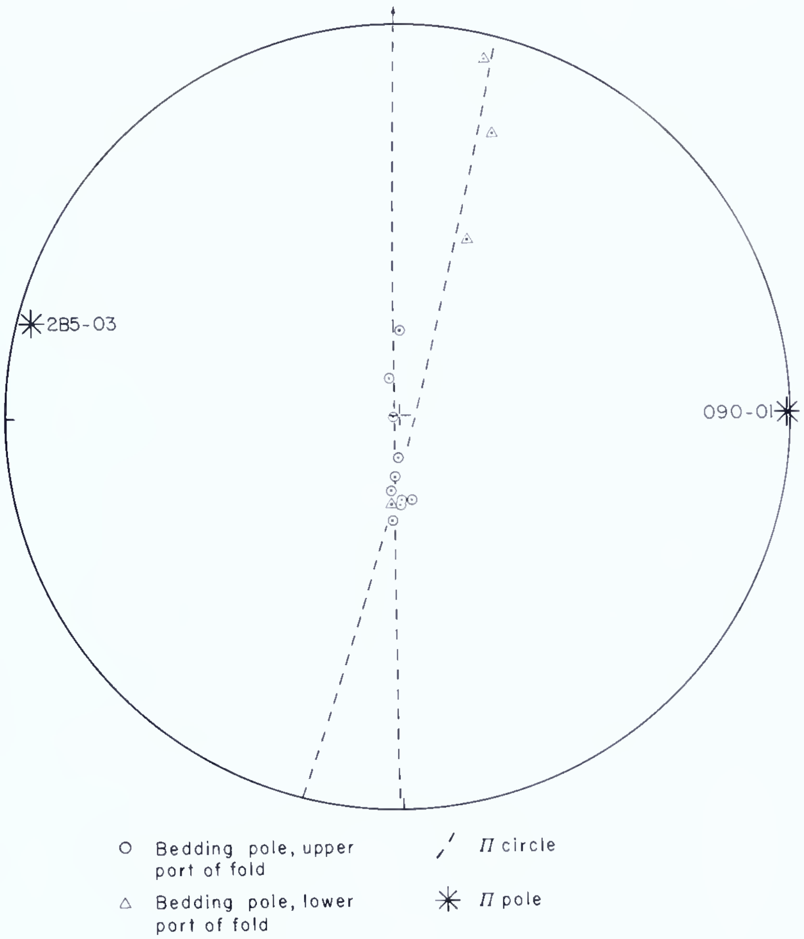

Figure 6. Stereogram of bedding poles from the upper and lower part of the fold in the western part of Lymehurst at the Loyalsock Township building (the fold has since been removed for parking lot expansion), showing the divergent trends between the two parts.

by 11 degrees, occur on several of the bedding surfaces (Figure 7). These indicate that two slip directions were operative during the deformation. The presence of two slickenline directions has been interpreted by Faill (1973) to reflect two distinct kinematic axes of rotation, one for each limb of the fold. Folds that have two rotation axes are noncylindrical and represent the overlapping of two structural trends in the same area.

A very open anticline is exposed in an abandoned quarry on the Allenwood Prison Farm just south of the mapped area. The fold axis plunges 3 degrees to the east-northeast (Figure 8), a trend reflecting the structural grain dominant to the west. At one exposure there are two diverging sets of slickensides. Although the axes of bed rotation cannot be determined from

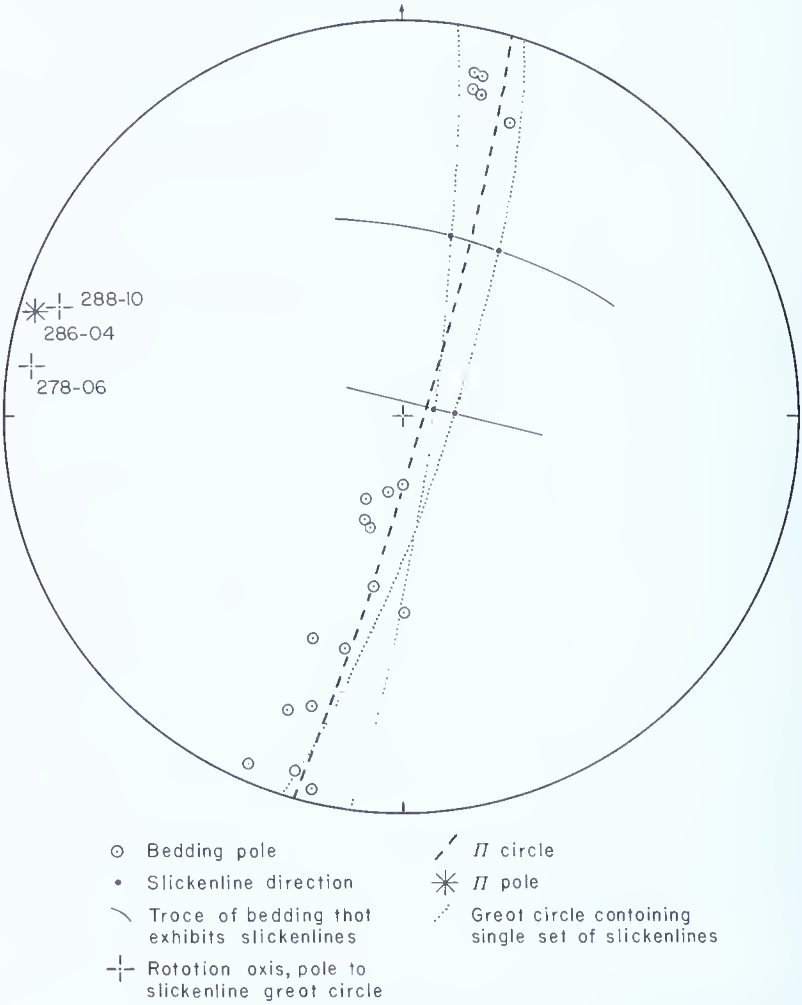
288-10
286-04
278-06
Bedding pole
Slickenline direction
Trace of bedding that exhibits slickenlines
Rotation axis, pole to slickenline great circle
Π circle
Π pole
Great circle containing single set of slickenlines

Figure 7. Stereogram of bedding poles and slickenlines on bedding for a fold in a quarry in the eastern part of Lymehurst. Two sets of slickenlines on single bedding surfaces represent two slip directions, indicating the influence of two axes of bed rotation. Both of the rotation axes diverge from the fold axis (hinge line), a characteristic of noncylindrical kink-band folds.

these readings alone, their northward plunge suggests the influence of th east-west structural grain that dominates the mapped area to the east. Al though these data are limited, this divergence indicates this locality is in a area of interfingering and overlapping tectonic trends.

KINK BANDS

Small, well-defined kink bands are not particularly common in this area the best examples occur in Hagermans Run and along Muncy Creek. Fo

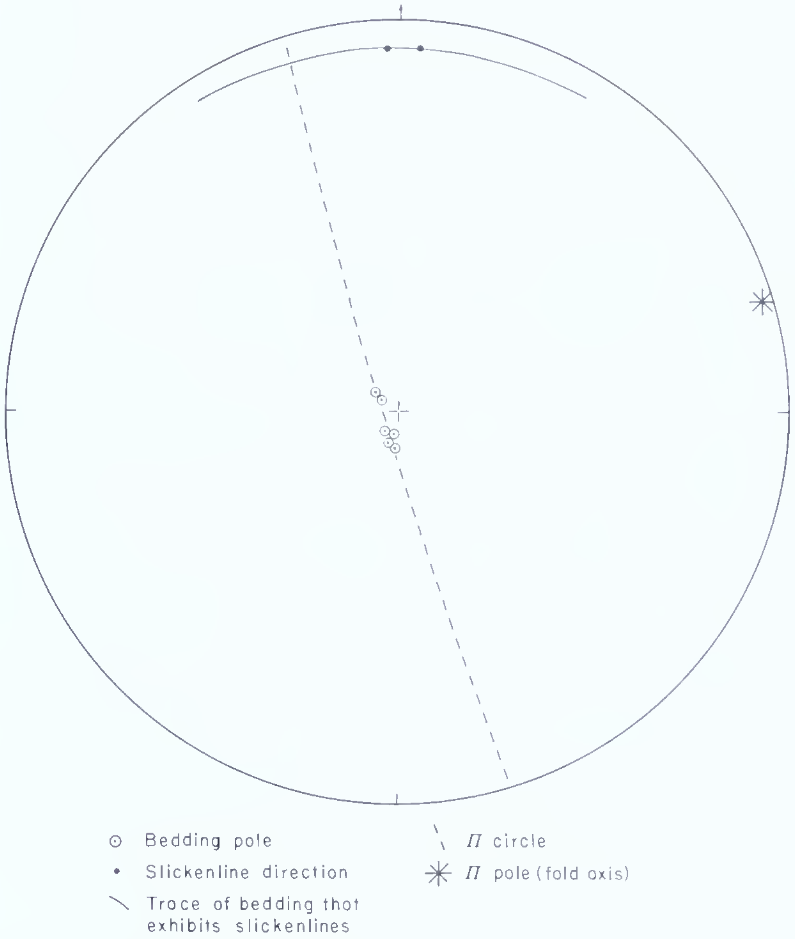

Figure 8. Stereogram of bedding poles and slickenlines on bedding for a fold in White Deer Valley (south of the mapped area). The northward plunge of both slickenline sets suggests east-west-trending rotation axes, whereas the east-northeast plunge of the fold axis indicates a diverging fold geometry.

the most part they are fourth order in size, and are observable within moderate-sized outcrops.

At Hagermans Run, kink bands 5 to 100 cm (2 to 40 in.) wide are developed in the Rose Hill Formation. These kink bands are subhorizontal in nearly vertical beds, and have kink axes that plunge very gently to the east-northeast (071 to 075), a trend consistent with that of the Nittany anticline in this vicinity. The amount of bed rotation ranges from 20 to 40 degrees, resulting in bedding being overturned within the kink bands.

The other locality where kink bands are well developed within these quadrangles is in a long (240 m, 790 ft) exposure of the Mifflintown Formation along the west bank of Muncy Creek (Figure 9). The significance of this exposure lies in the density of small structures, its location on the crest of the first-order Nittany anticline, and the three structural trends that are present at this single locality.

The kink bands themselves are quite variable. Two in the north end (at 30N and 40N meters (98N and 131N ft) from the power line) are poorly developed, having only a few degrees rotation of bedding (mostly in strike). Most of the other kink bands are more fully developed and have easily identifiable kink planes and large amounts of bed rotation. Six of the kink bands are south dipping and two are north dipping; at the south end, two oppositely dipping kink bands form a conjugate fold (Figure 10). The kink bands are fairly narrow, from 1.5 to 8 m (5 to 26 ft) in width. Between the kink bands are broader zones within which the bed attitude is constant or changes gradually by small amounts. Overall, the bedding dips eastward, consonant with the plunge of the Nittany anticline. However, the kink bands and broad warpings define two other trends as well. In the south end of the outcrop, the bedding poles at the stations from 160S to 120S (Figure 9D), define a single great circle, the pole of which plunges 095–10 degrees (see stereograms A–D in Figure 9), fairly close to the local plunge of the Nittany anticline (086–11). The bedding poles between 50S and 90S (Figure 9C) define a similar plunge, but those in the broad warp between 90S and 120S (Figure 9C) define a plunge of 071–11 degrees, a trend that is dominant in the Hagermans Run vicinity (072–07), but that has not been seen anywhere else east of there. On the other hand, the fold between 50S and 35S plunges 115–20 degrees (Figure 9B), a trend parallel to the one in the Lymehurst vicinity, and also has not been observed elsewhere. From 35S to 80N (Figure 9A) at the north end of the exposure, the beds dip generally eastward, with two exceptions: one kink band at 17S–10S has a kink-axis plunge of 103–11 degrees (close to the Nittany anticline trend); the other kink band plunges 120–10 degrees (subparallel to the Lymehurst trend). Thus, three structural trends common in widely disparate areas are all present within this single outcrop: the Hagermans Run trend, the Lymehurst trend, and the Nittany anticline trend. The interfingering of tectonic grain in this outcrop is representative of the interfingering that exists on a much larger scale throughout the Valley and Ridge province (Faill, 1973).

FAULTS

Faults are not common in the Montoursville South, Muncy, and Hughesville quadrangles; evidence for those that are present appears in three forms: offsets of contacts, offsets of bedding, and slickenlines on fracture surfaces. Three faults are large enough to be shown on the map.

The Williamsport fault in the Susquehanna River valley south and west of Lymehurst is the largest in the mapped area. The fault trace is entirely con-

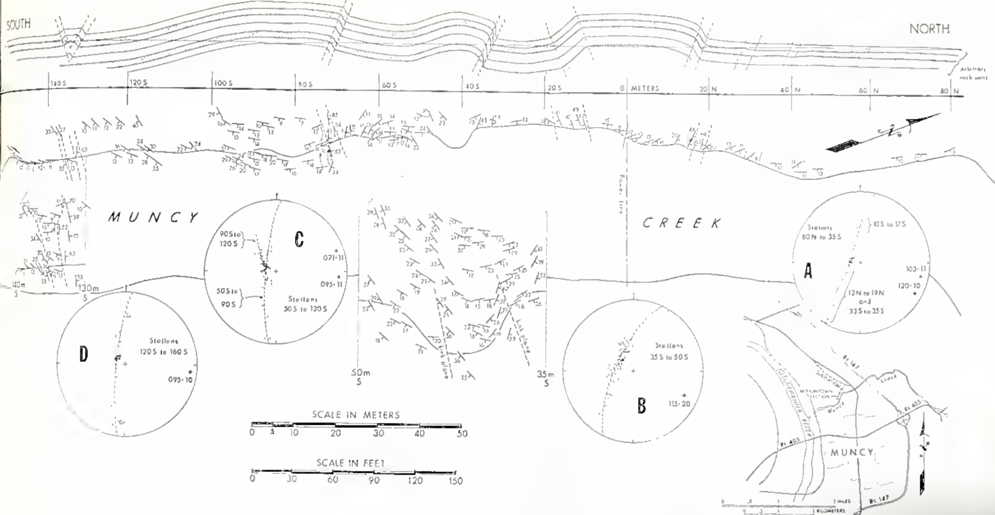

Figure 9 Map and inferred cross section of a long outcrop of the Mifflintown Formation along the west bank of Muncy Creek north of Muncy (see inset map for location). This cluster of kink bands is unusual, and defines three different structural trends, as shown in the stereograms. Two areas, between 140S and 130S m and between 50S and 35S m, have been enlarged two and three times, respectively, because of the high density of data.

Fig

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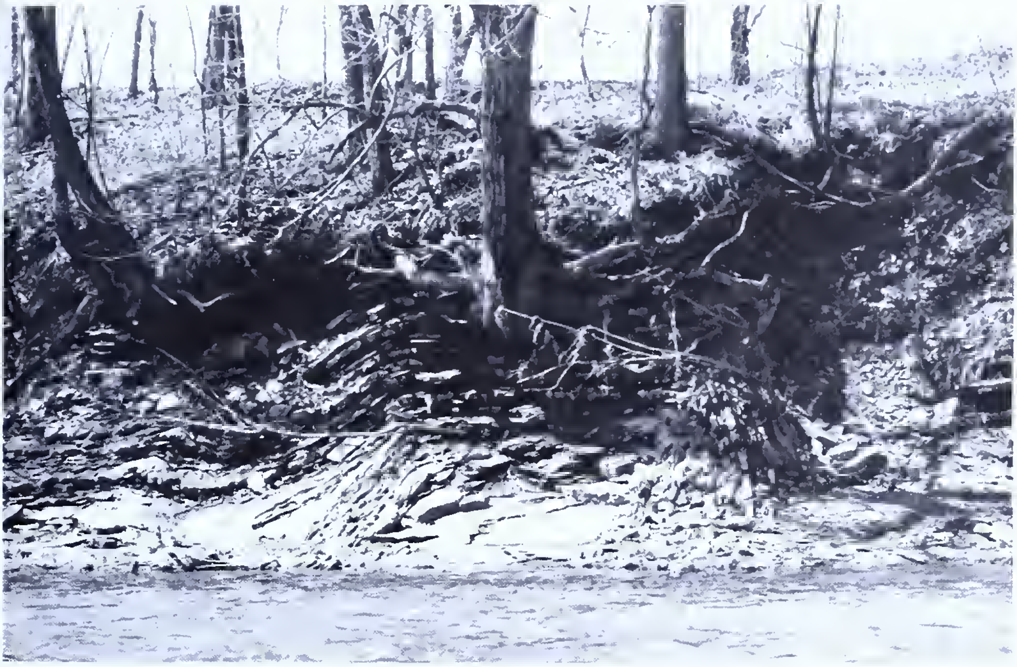

Figure 10. Conjugate fold resulting from two oppositely dipping kink bands at approximately 134S m on the map in Figure 9.

cealed under alluvium. Presence of the fault is inferred primarily from the Ridgeley sandstone encountered in holes drilled for bridge structures along U. S. Route 220 in southern Kenmar and Faxon. With the Ridgeley this far north, the absence of a fault would require moderately steep dips in the Middle Devonian rocks to the north, and quite gentle dips in the Silurian rocks to the south, a situation for which no evidence exists. The fault is inferred to be a thrust, dipping south at 23 degrees and having a maximum displacement of approximately 600 m (2000 ft).

Another sizable fault is a transverse fault in White Deer Valley at the southern edge of the mapped area. This fault, inferred from an apparent offset of the Onondaga and Old Port contacts, trends 032 degrees, is probably subvertical, and has a right-lateral displacement of 150 m (500 ft).

A third fault is also a transverse fault, on the crest of North White Deer Ridge. This fault, inferred from an apparent offset of Tuscarora-Juniata sandstone ledges, trends 018 degrees and has a displacement of 20 m (65 ft). It appears to be a subvertical right-lateral fault similar to the one in White Deer Valley.

Two faults were observed in outcrops (quarries). A fault in the Lime Bluff quarry northeast of Muncy offsets Tonoloway beds in the southeastern pit, with displacement of not more than 20 m (60 ft). The fault dips 33 degrees to the northeast (in the direction 034 degrees). This is probably a large wedge fault, with displacement of the overlying block southwestward over the underlying block. This fault projects into a galena-bearing vein elsewhere in the quarry, and this mineral occurrence may be related to it (see Mineral Resources section).

A small transverse fault was observed in the north wall of a quarry in the north-dipping Ridgeley sandstone east of Fairview Drive in Montoursville, 175 m (575 ft) north of the north edge of the Montoursville South quadrangle. Offset of the Ridgeley-Onondaga contact was 25 cm (10 in.), down on the west; the dip was 89 degrees to the east-southeast (101 degrees azimuth). Slickenlines were not observed, so the displacement could have been vertical, horizontal (a left-lateral strike-slip fault), or intermediate between these two.

The only other offsets observed within the mapped area were offset fractures on the west side of Twin Run, in the drainage gully immediately south of Pa. Route 220.

The other evidence of fault movements, slickenlines on fractures, is not profuse. Figure 11 summarizes the measured data. Most of the fault poles lie relatively close to the bedding pole (at the center of the stereogram), indicating that the majority of these faults are wedge faults. The concentration of slickenlines plunging gently north reflects the east-west structural grain that dominates this mapped area. The few slickenlines plunging northwest and southeast represent the structural trend that dominates the Hagermans Run vicinity. Most of the north-plunging slickenlines were measured in Hagermans Run, indicating that although the apparent structural trend is northeast, the east-west trend is also present, another example of the interfingering (or overlapping) of structural trends. The northeast-southwest-plunging slickenlines, reflecting the Lymehurst and Muncy Creek trend, are from White Deer Valley, Muncy, and on the north side of Bald Eagle Mountain between South Williamsport and Sylvan Dell. The last locality has slickenlines plunging northward as well.

No other faults have been observed or inferred within these quadrangles, although the wide extent and thickness of the surficial deposits could easily mask even sizable faults. However, available data do not suggest or require the presence of any additional faults.

CLEAVAGE

Cleavage is not a common structure within this mapped area. It appears only locally in the Reedsville, Bloomsburg, Keyser, and (rarely) the Tonoloway and Trimmers Rock Formations.

The best developed cleavage is in the Reedsville Formation on the north side of Mosquito Valley. Here, the shales and interbeds of siltstone dip

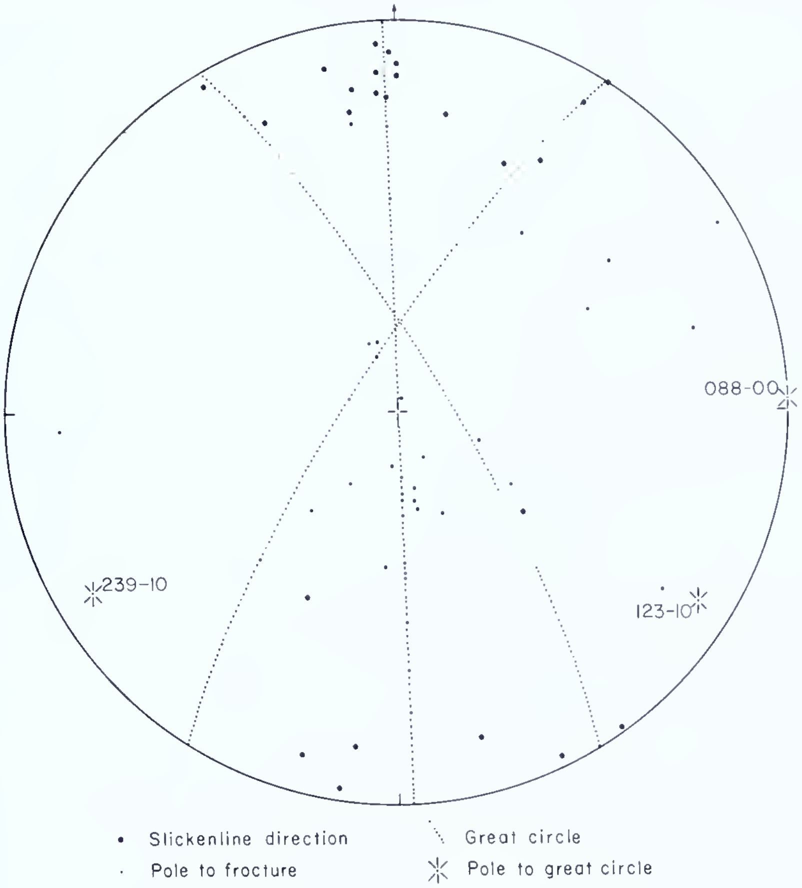

Figure 11. Summary of all slickenlines on fractures throughout the three quadrangles. Data have been rotated such that bedding is horizontal. The three structural trends prevalent in the mapped area are reflected by the slickenlines.

moderately to steeply north—the cleavage dips to the south, perpendicular to bedding (Figure 12). The cleavage is quite planar, and pervades the more argillaceous layers to the extent of obliterating the original bed-parallel fissility—bedding can be ascertained with certainty only by the presence of the silty layers.

Cleavage is most common in the Bloomsburg, but not well developed. The cleavage consists of faint, closely spaced, very irregular partings which cause the rock to disaggregate readily into small chips. The cleavage is generally perpendicular to bedding, regardless of bed attitude, and has a strike subparallel to that of bedding. Lack of sufficient data because of the overlying surficial deposits precludes a more extensive analysis of the Bloomsburg cleavage.

Cleavage is present in the lower part of the Keyser Formation, in the nodular limestone of the Byers Island Member. The cleavage consists of

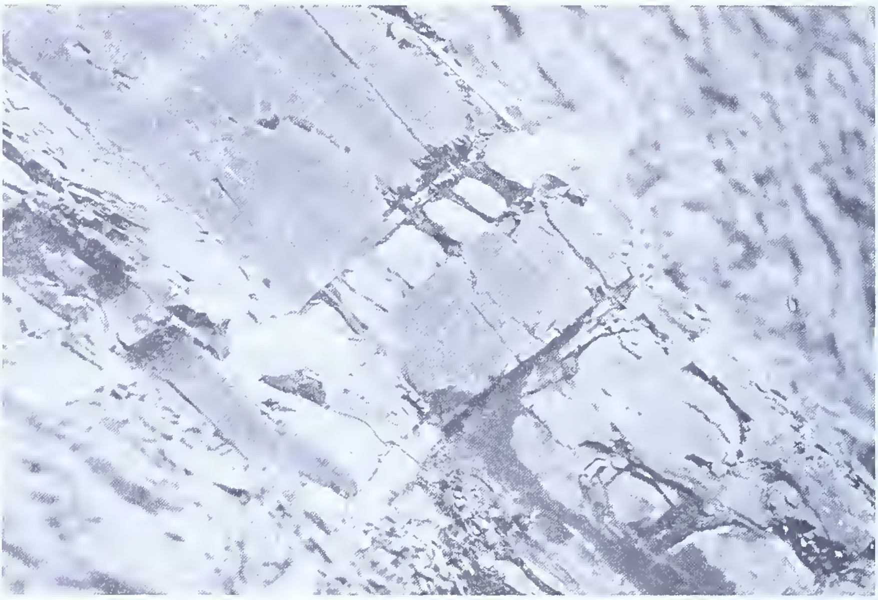

Figure 12. Pervasive cleavage developed in argillaceous beds of the Reedsville Formation, in the easternmost large borrow pit on the north side of Mosquito Valley. Bedding, as indicated by the light-colored, 4-cm-thick siltstone layer, dips to the north (left); the cleavage dips to the south (right). Original bed-parallel fissility has been obliterated.

fairly wide (1 cm) zones of clay-rich calcisiltite between microlithons of purer limestone.

A faint cleavage was also observed in the Trimmers Rock Formation, south of Clarkstown, near the hinge of the White Deer syncline. It consists of closely spaced parallel surfaces which probably developed by dissolution of the quartz grains, with residual accumulation of clay material in the surfaces, similar to the cleavage described elsewhere in the Valley and Ridge province (Nickelsen, 1974a). This cleavage is perpendicular to bedding and strikes east-west, subparallel to the trend of the White Deer syncline. This area also exhibits significant fossil distortion, as is discussed in a following section.

PLANAR VEINS

Within the purer limestone beds and laminated beds of the Tonoloway and Keyser Formations are planar veins, most of which are perpendicular to bedding and subparallel to the local fold axis (strike veins). A small number of them diverge from the fold axis 5 to 10 degrees, an occasional one by as much as 25 degrees. The veins are exceptionally planar, and extend across outcrops. They are very thin (0.02 to 0.08 mm) and rather closely spaced (5 to 20 mm). All the veins are filled with coarse calcite, although some of them have subsequently been widened and this more recent separation is filled with quartz. Their orientation, parallel to that of cleavage, might suggest they were formed by pressure solution, but their planarity and the absence of any clay accumulation in them indicates they are neither stylolites nor cleavage. Most likely, these structures originated as fractures that opened and permitted mineral deposition. These structures therefore reflect an extension of the rock perpendicular to the axial surfaces, and were probably formed later than the compressive structures, such as folds, cleavage, and distorted fossils.

A few quartz-filled veins have also been observed in fractures that are perpendicular to the local fold axes (dip veins). These veins are generally much thicker (up to 5 mm) and occur in other lithologies as well as in limestones. They probably had a similar origin (deposition in opened fractures) and were contemporaneous with the quartz phase of the strike veins.

DISTORTED FOSSILS

Kink-band folding, and its attendant wedge and transverse faulting, is a relatively brittle process, utilizing slip on bedding and fault surfaces for developing the fold structures. Deformation of the beds themselves is minimal except where they are bent in fold hinges and kink planes. Fossils within the beds, however, exhibit shape distortions—brachiopods are not bilaterally symmetrical, and crinoid columnals are not circular. This type of distortion is present throughout and beyond the mapped area, and is not associated only with particular local structures.

These distortions were imparted after these fossils were deposited, indicating that some deformation within each bed has indeed occurred. In an effort to evaluate this structural feature, distorted fossils were collected from 10 different sites within and near the mapped area (Figure 13).

Although all the fossils exhibit distortion, measurements were made only on crinoid columnals because, being initially circular, their present elliptical shapes provide a direct and simple means of measuring the amount of strain and the direction of maximum extension. The samples are from the Reedsville, Trimmers Rock, or Lock Haven Formations, consisting of siliceous subgraywackes that have grain sizes ranging from 0.009 to 0.110 mm (siltstone and sandy siltstone). When the samples were collected, bedding strike and dip were marked on them (except for three which were float blocks) so that the actual orientations of maximum shortening and extension could be determined. Most of the columnals were disaggregated from the original stem; because of their disk shape, they lay flat in the bedding planes. Occasionally a crinoid stem was found lying intact in bedding, which provided strain measurements perpendicular to bedding. Rarely, the original calcite crystal comprising each columnal was preserved; usually it has been dissolved, leaving behind the mold, on which the measurements were made.

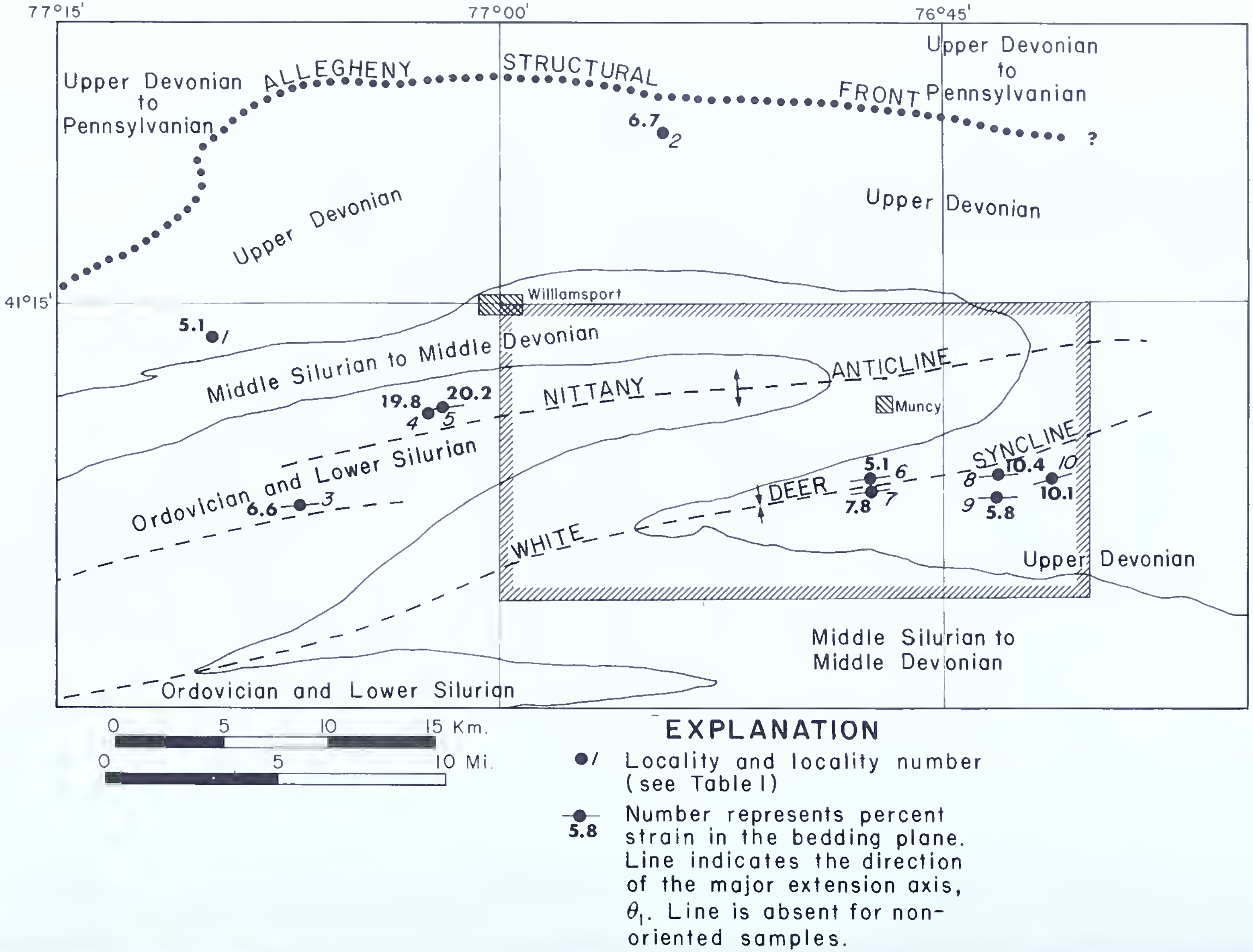
77°15'
77°00'
76°45'
41°15'
Upper Devonian to Pennsylvanian
ALLEGHENY STRUCTURAL FRONT
Upper Devonian to Pennsylvanian
?
6.7 2
Upper Devonian
Upper Devonian
Williamsport
5.1 1
Middle Silurian to Middle Devonian
NITTANY ANTICLINE
Muncy
19.8 4
20.2 5
Ordovician and Lower Silurian
6.6 3
WHITE DEER SYNCLINE
5.1 6
7.8 7
8 10.4
10 10.1
9 5.8
Upper Devonian
Middle Silurian to Middle Devonian
Ordovician and Lower Silurian
0 5 10 15 Km.
0 5 10 Mi.
EXPLANATION
● 1 Locality and locality number (see Table I)
5.8 Number represents percent strain in the bedding plane. Line indicates the direction of the major extension axis, θ1. Line is absent for non-oriented samples.

Figure 13. Simplified geologic map of the area surrounding the three quadrangles, showing localities where distort-

Three hundred eighty-five columnals were measured among the 10 samples, all but 22 of which lay in the bedding plane. The maximum extension was found to lie in the bedding plane, subparallel to the local fold axis, regardless of the dip of bedding (Table 1; Figure 13). The axis of minimum extension (maximum shortening) was usually perpendicular to bedding (e.g., locality 7 in Table 1). However, at locality 3, a few of the columnals normal to bedding exhibited more shortening parallel to bedding, whereas in the others, the major shortening was perpendicular to bedding. The reason for this is unknown. The orientation of the calcite crystal may be a factor, because the strength of calcite varies considerably depending on the direction in which the crystal is stressed.

Table 1. *Summary Data of Distorted Fossils*

Locality*	ϵ_{12}**	θ_1	ϵ_{13}	ϵ_{23}	Bedding	Formation
1	5.10	—	—	—	198-13	Lock Haven
2	6.72	—	—	—	358–73	Lock Haven
3	6.63	085	7.72	−6.54	051–10	Reedsville
4	19.80	—	—	—	012–94***	Reedsville
5	20.20	$\sim$084	—	—	358–59	Reedsville
6	5.08	083	—	—	186–25	Trimmers Rock
7	7.83	083	26.32	16.18	348–09	Trimmers Rock
8	10.37	087	—	—	290–02	Trimmers Rock
9	5.84	089	—	—	008–07	Trimmers Rock
10	10.05	074	—	—	000–02	Trimmers Rock

*See location map, Figure 13.

**ϵ is the natural strain (in percent) in one of the three principal planes of the strain ellipsoid. The subscript 1 is the axis of maximum extension and is usually subparallel to the local fold axis; its direction is given by θ_1. The subscript 2 is the intermediate strain axis. The plane 1,2 corresponds to bedding. The subscript 3 is perpendicular to bedding and is usually the direction of maximum shortening.

***Overturned beds.

More importantly, the major extension in the bed-normal columnals is either perpendicular or parallel to bedding—it is not at some other direction, except in samples exhibiting a strong cleavage oblique to bedding. This indicates that bedding coincides with one of the principal planes of the three-dimensional strain ellipsoid. This aspect places parameters on the origin of this flow deformation. Had flow occurred during or after folding, the stress field and the resulting strain would not be congruent with bedding, but would conform to the fold geometry. Because this flow is congruent with bedding, it is concluded that the deformation that resulted in the fossil distortion preceded folding, producing a general vertical thinning of the beds and elongation in an east-west direction.

A few further observations can be made. First, it is not coincidental that the major axis of extension is east-west, subparallel to the local east-west fold axes. In other parts of the Valley and Ridge province, where the local fold axes trend differently, north-south or northeast-southwest, the major extension axes of the fossil distortion similarly parallel those local fold axes (Faill, 1977). So, although the flow deformation precedes folding, there appears to be a definite relationship between the two. Secondly, within this data from the Williamsport-Muncy area, a correlation appears to exist between amount of strain and steepness of bedding dip. The two localities that had the largest strains (numbers 4 and 5) have moderately steep to overturned dips, whereas most of the other localities exhibit lower strains and gentler dips. However, this correlation is not very strong, because locality 2 possesses a fairly low strain despite the steep dip, and localities 8 and 10 possess moderately large strains with extremely low dip. Data from other parts of the Valley and Ridge province indicate that no relationship exists between amount of deformation and steepness of bedding dip (Faill, 1977). A search for an explanation for the apparent strong correlation in the Williamsport data leads to a third observation—the influence of cleavage on the magnitudes of fossil strain. In most samples, cleavage is not present (at least not macroscopically). However, samples 4 and 5 exhibit a well-developed cleavage, and it is presumed that cleavage has enhanced the distortion. A less faint cleavage is present in samples 8, 9, and 10, which would explain the moderately large strains in 8 and 10, but not the lower strain in 9.

In summary, the strain-fold axis coincidence suggests that the fossil distortion and the kink-band folds are two phases of a single deformational period. The lack of correlation between the amount of strain and the bedding dip indicates that the flow deformation represented by the distorted fossils occurred in the early stages of the folding, before the folds developed any appreciable amplitude. The reason for the variation among the localities, even those close together (as numbers 8 and 9), is not known.

FRACTURES (JOINTS)

Fractures, or widespread ruptures in the rock, fall into two general categories: extension fractures, formed parallel to the maximum deforming stress, with initial movement perpendicular to the fracture; and shear fractures, formed at a moderate angle (30 degrees ± 10 degrees) to the maximum deforming stress, with initial movement parallel to the fracture. Shear fractures have been discussed under faults and will not be further considered here.

Extension fractures can be divided into two broad categories: (1) irregular and (2) planar (joints). The irregular fractures vary from smoothly undulatory to very angularly rough. They are generally not very extensive, and are often restricted to single beds. No orientation data were collected on fractures in this category because their irregularity precluded meaningful measurements.

More common are the planar and smooth extension fractures, which are also called joints. All of the fracture data on the geologic map were measured on these planar fractures. The majority of the joints are subperpendicular to bedding (70 percent are inclined more than 80 degrees to bedding, 90 percent more than 70 degrees; see Figure 14). The bedding dips are gentle over much of the mapped area, and the joints tend to be subvertical (62 percent dip more steeply than 80 degrees, 83 percent more than 70 degrees; see Figure 14). No significant differences exist in either dip or inclination to bedding as a function of location within the major folds, whether in the north or south limb of the Nittany anticline, in the north or south limb of the White Deer syncline, or in the hinges of either fold.

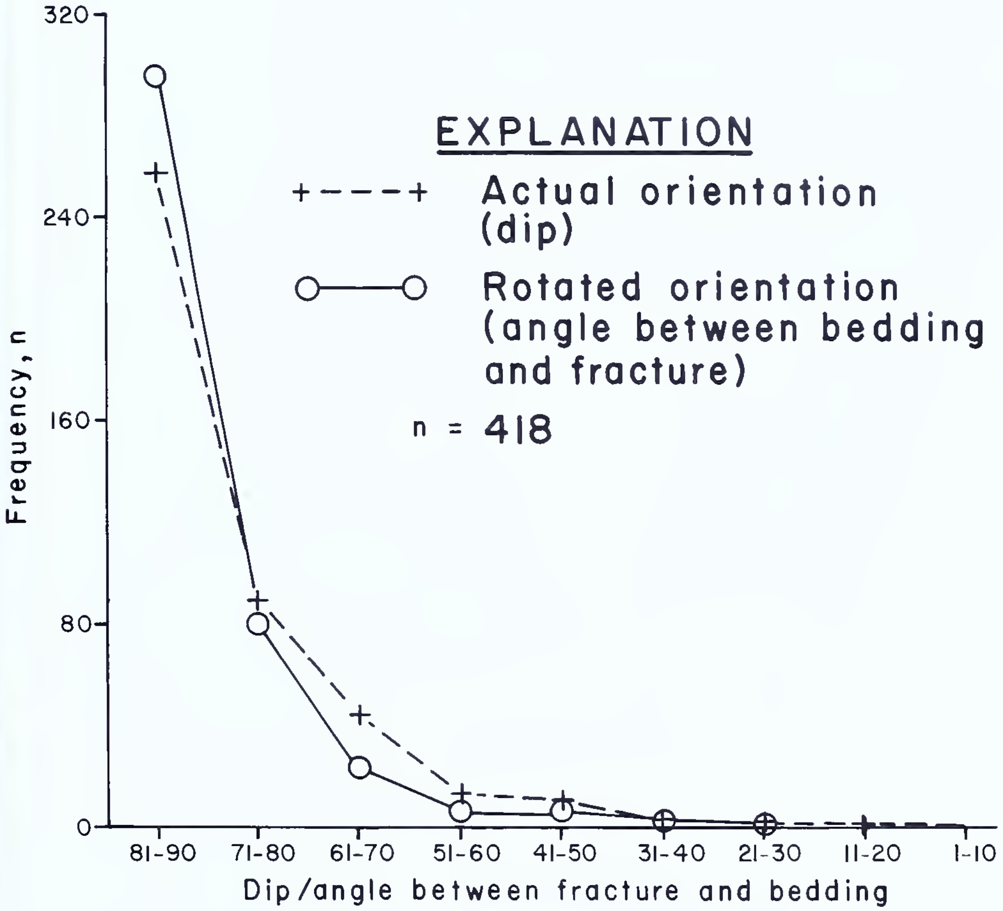

Figure 14. Attitude of fractures. The crosses indicate the number of fractures that dip within each 10 degree interval. The circles indicate the number of fractures that are inclined to bedding within each 10 degree interval. The two curves are similar because of the generally gentle dip of bedding throughout the three quadrangles.

The trend of these fractures is more complex. The stereograms of fracture poles for each of the three quadrangles (Montoursville South, Muncy, and Hughesville; Figures 15, 17, and 18, respectively) demonstrate the near perpendicularity of the fractures to bedding. (In each stereogram, the poles to fractures at every outcrop have been rotated about the bedding strike by an amount equal to the bedding dip. The bedding pole is thus the same for all the outcrops, at the center of the stereogram.) Another prominent aspect

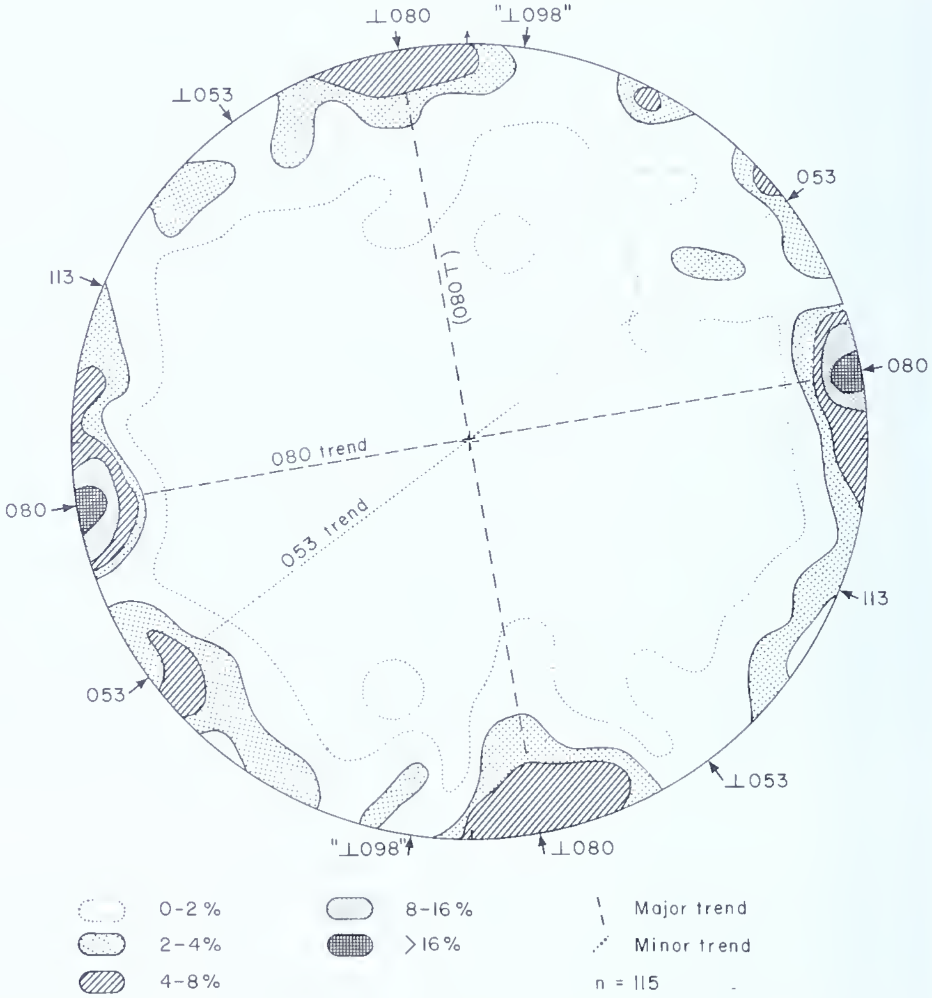

Figure 15. Stereogram of fracture orientations (poles, rotated about the bedding strike by an amount equal to bedding dip) measured in the Montoursville South quadrangle (except for those in the Lymehurst area, at the north edge of the quadrangle, which are shown in Figure 16). The densest concentration of poles (representing the dip fractures) define a trend of 080 degrees, subparallel to the fold axis; a less dense concentration (representing the strike fractures) lies at right angles to the 080 trend. A minor concentration (of no more than 8 percent) reflects the 053 trend that is dominant in the Hughesville quadrangle (Figure 18).

(especially in Figures 15 and 18) is the clustering of fracture poles; one cluster (representing dip fractures, those whose trace on bedding is subparallel to the dip direction) is parallel to the local fold axis, the other (representing strike fractures) is at right angles to the fold axis.

In the Montoursville South quadrangle (Figure 15), a very persistent trend (080 degrees) extends over the entire southern three fourths of the quadrangle, despite the change in trends of both the Nittany anticline and

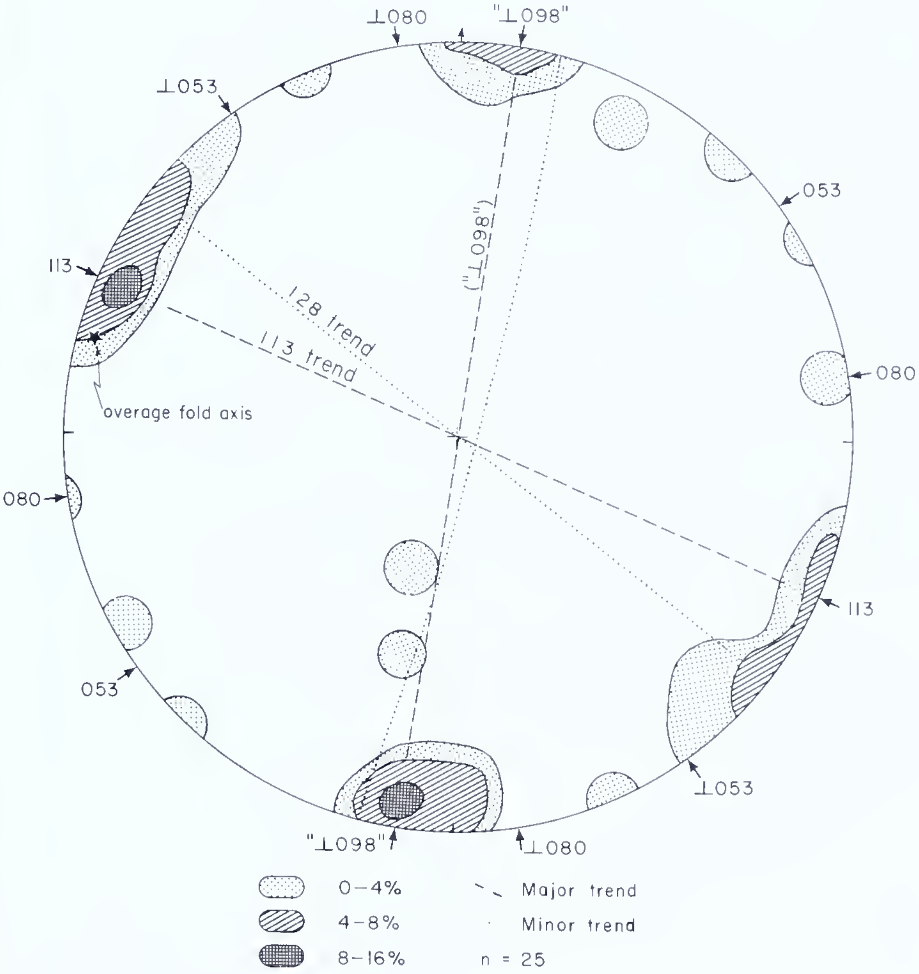

Figure 16. Stereogram of fracture orientations (poles, rotated as in Figure 15) measured in the northern quarter of the Montoursville quadrangle, mostly around Lymehurst. Two strong maxima occur, one trending 113 degrees (representing dip fractures), the other (representing strike fractures) trending 188 degrees (perpendicular to a virtual "098" trend). A less dense concentration trends 128 degrees. Interestingly, the 113 maxima diverges by 10 degrees from the local fold-axis orientation (Figure 5). In contrast to elsewhere in the mapped area, the strike fractures are not orthogonal to the dip fractures.

the White Deer syncline. In contrast, a distinctly different pattern exists in the Lymehurst area in the northern part of the Montoursville South quadrangle (Figure 16). Two dense concentrations of fracture poles occur, but neither maximum coincides with those further south, nor are they perpendicular to each other (although they are subperpendicular to bedding). One of the two trends is 113 degrees, only 10 degrees southeast of the local fold axis (Figure 5). The other concentration trends 188 degrees, perpendicular to a virtual "098" trend. This fracture pattern apparently reflects the local fold geometry, but why the two fracture sets are not orthogonal is not known.

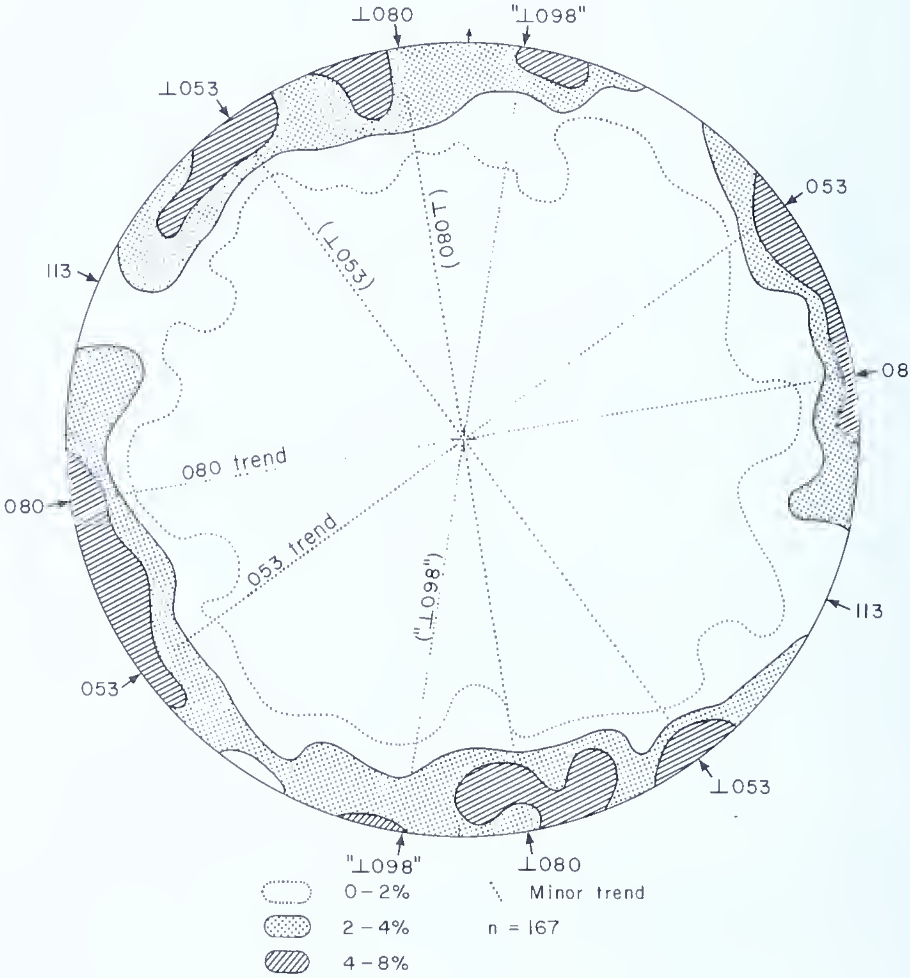

Figure 17. Stereogram of fracture orientations (poles, rotated as in Figure 15) measured in the Muncy quadrangle. A general east-northeast trend is present, but is not well defined by a small, dense cluster. This dispersion may represent two different trends present in this quadrangle, one (080) characteristic of Montoursville South to the west, the other (053) dominant in the Hughesville quadrangle to the east.

In the Muncy quadrangle adjacent to the east, such well-defined patterns do not exist (Figure 17). Nowhere does the pole density exceed 8 percent (maximum density in Montoursville South is 18 percent), and there is no single, well-defined trend. Rather, the dip-fracture orientations range rather uniformly between 050 and 085, suggesting that they comprise a mixture of two trends, the 080 trend of the Montoursville South quadrangle to the west, and the 053 trend of the Hughesville quadrangle to the east. Three clusters of strike-fracture poles are present, one perpendicular to the 080 trend, another the 053 trend, and the third perpendicular to the ''098'' trend of Lymehurst. As with the kink bands and folds, several different tectonic trends of fractures appear to interfinger and overlap in the Muncy quadrangle.

The fracture-pole pattern in the Hughesville quadrangle (Figure 18) is similar to that in Montoursville South—a dense concentration of poles having a somewhat less dense grouping at right angles, again demonstrating that the dip and strike fractures are at right angles. However, the trend defined is 053, quite different from the 080 trend in Montoursville South, and also diverging considerably from the 064 to 080 trends of the axial traces of the Nittany and White Deer folds, the only significant large structures in this quadrangle. Virtually no dip fractures of the 080 trend are present here, but there is a representation of the strike fractures. A third low maxima defines a trend perpendicular to the 113 trend of the Lymehurst area. So it seems that although fractures of the 053 trend dominate the Hughesville quadrangle, fractures having orientations typical of other nearby areas are also present.

Overlapping of fracture trends (or sets) has been recognized in the Allegheny Plateau to the north (Parker, 1942) and west (Nickelsen and Hough, 1967). Nickelsen (1974b) has shown that these trends persist southward into the Valley and Ridge province, an aspect that is supported by the data in this report. For example, the systematic shale joints in the Plateau immediately north of Williamsport (Nickelsen and Hough, 1967, Plate 3, set A) strike 147 degrees, an orientation that persists from New York southwestward to the Altoona-DuBois area and is parallel to the 053 (fracture pole) trend of Hughesville. Similarly, set D of Nickelsen and Hough, restricted to the Plateau between Williamsport and Lock Haven, trends 170 degrees parallel to the 080 trend of Montoursville South. It appears, then, that these locally measured orientations are indeed regional in extent, and cross major structural boundaries such as the Allegheny Structural Front. Nickelsen and Hough (1967) conclude that the systematic shale joints preceded folding and faulting (but developed in response to the stresses responsible for the folds and faults.) The complete absence of the two regional orientations at Lymehurst (Figure 16) suggests that jointing developed in shales earlier than in limestones, and that the limestone fractures reflect only the local structural trends.

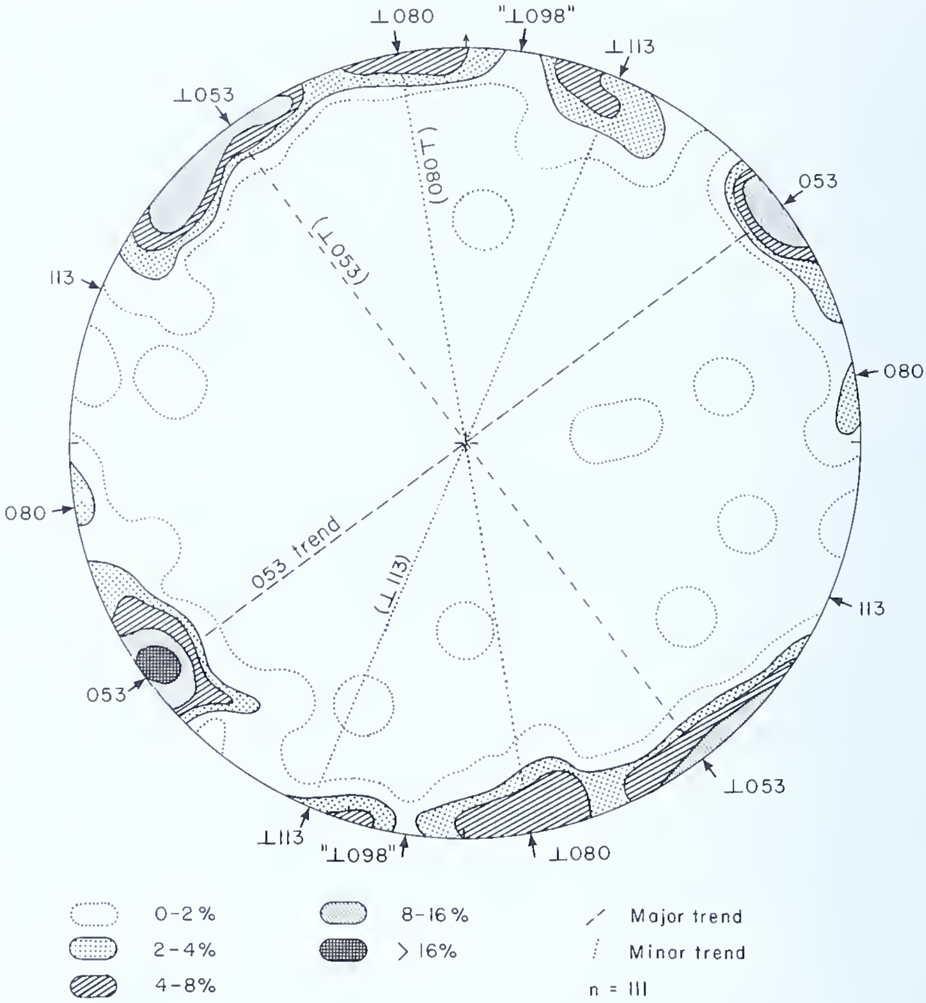

Figure 18. Stereogram of fracture orientations (poles, rotated as in Figure 15) measured in the Hughesville quadrangle. The densest concentration (representing the dip fractures) defines a trend of 053 degrees, and a lesser concentration (representing the strike fractures) is orthogonal to it. Two other even less dense clusters occur perpendicular to 080 and 113.

Fracture density is difficult to evaluate because it is dependent upon bed thickness, orientation, and lithology. Generally, fracture spacing is directly related to bed thickness, and the spacing between fractures decreases with decreasing thickness of beds. The largest and most pervasive joints are dip fractures of very constant orientation, and are most prominently expressed in the homogeneous shales of the Rose Hill, Bloomsburg, Marcellus, and Mahantango Formations and parts of the Trimmers Rock Formation. The spacing between these joints is quite large, ranging from 0.5 to 2 m (1.6 to 6.6 ft). In shales, strike fractures are generally not as well developed; they do not extend for great distances through the rocks, and they are usually subplanar to somewhat irregular. Their spacing is less than that of the dip fractures.

In siltstones and sandstones, the joints are usually restricted to single beds and thus the extensive dip fractures are not encountered as frequently in these rocks. This is particularly evident in sequences of interbedded siltstone and shale. Both dip and strike fractures tend to be planar, and there seems to be a greater variety of orientations in the more silicified rocks. Fracture density appears to be closely related to bed thickness; spacing between fractures ranges from one to two times the bed thickness. There is also a tendency for a higher density of strike fractures as compared to dip fractures.

The fractures in limestones are in many respects similar to those in siltstones and sandstones. Strike fractures occur somewhat more frequently than dip fractures, and diagonal fractures are also rather common.

ENVIRONMENTAL GEOLOGY

The relevance of geology to man's activities has increased with urban and suburban growth in the Montoursville-Muncy vicinity. The different and sometimes contrasting properties among the various rock and unconsolidated surficial materials sometimes presents complex problems for man. These properties include: topography; surface and subsurface drainage; nature of weathering and depth to bedrock; degree of natural fracturing; difficulty of excavation; slope stability; foundation stability; mineral or economic potential; and amount and quality of the groundwater.

Each unit mapped in this area is evaluated with respect to these categories, and the evaluations are listed in the "Environmental Characteristics" column in the legend on the geologic map. The evaluations are necessarily generalized; for specific uses and locations, a detailed geologic on-site evaluation should be made.

Following is a list and explanation of the environmental characteristics described for each formation in the map legend.

Topography—This includes landforms (valleys, hills, mountains) that are usually developed on the lithic unit. Valleys tend to develop on limestones; low hills on shales and siltstones; higher hills on interbedded siltstones and sandstones; mountains and ridges on the thick, more siliceous sandstones. Slope steepness refers to natural slopes. The degrees of steepness are defined as follow: gentle—0 to 5 degrees; moderate—5 to 15 degrees; steep—15 to 35 degrees; very steep—35 to 80 degrees; and subvertical—80 to 90 degrees.

Drainage—Much of the rainfall infiltrates the soil and bedrock to recharge the groundwater supply. The remaining amounts usually drain into the major rivers through a network of smaller streams. The exception to this is in areas underlain by limestones in which extensive underground channels are developed within the soluble bedrock. Much of the drainage flows through these channels and the surface drainage network is only poorly developed. The only prominent example of this is The Sink, a large sinkhole in the northern part of White Deer Valley west of Maple Hill. This sinkhole extends for 2.2 km (1.4 mi) along a narrow valley underlain by the Tonoloway and Keyser Formations. Although one stream flows into The Sink, none flow out. Presumably it is connected to Spring Creek to the west by underground channels. After Tropical Storm Agnes in 1972, the water level in this sinkhole rose dramatically, inundating the road and Community Center of Maple Hill under 1 to 2 m (3 to 7 ft) of water. Poor surface drainage and closed depressions are also present in areas of thick glacial till, particularly in White Deer Valley north of Montgomery and west of U.S. Route 15.

Weathering—The alteration and disintegration of rock varies considerably with lithic type. Units having low resistance to weathering (such as some shales) tend to possess thick (greater than 3 m, or 10 ft) soil and partially weathered material above fresh bedrock, whereas units of high resistance generally have little or no such material (less than 1 m, or 3 ft) and outcrops are common. Erosional resistance also relates to topography—those rock formations having high resistance tend to underlie the higher terrains. Limestones are a class by themselves; their resistance to mechanical weathering is high, but very low with respect to chemical weathering. As a result, the depth to bedrock is highly variable, and sinkholes and pinnacles are common.

Fractures—The nature and degree of fracturing varies considerably with lithology. Fractures can be divided into two general groups: planar, which extend through one or more beds with no change in orientation; and nonplanar, consisting of curved or irregular fractures. "Fractures well developed" means that a high proportion of the fractures are planar; "fractures poorly developed" indicates that most of the fractures are nonplanar. Close or wide spacing refers to the density of fractures (number of fractures per meter) and applies only to the planar type. The nature and density of fractures is important in slope and foundation design. Fractures also provide an important secondary porosity to the bedrock for the movement of groundwater.

Engineering qualities—Excavation difficulty, cut-slope stability, and foundation stability are as much a function of depth to bedrock as of lithology; all three tend to improve with depth into fresher bedrock. Difficult excavation generally requires blasting and heavy equipment, moderate difficulty requires less blasting, and moderately easy indicates the rock can be ripped and dug without blasting. In cut slopes, low stability indicates instability even with minor undercutting or loading; high stability applies to those rocks that can maintain a steep or vertical slope indefinitely. Units of low foundation stability would require "floating foundations," or foundations in solid bedrock for heavy loads; moderate might require piers or piles; whereas in high-stability areas, conventional footings would be adequate for heavy structures. Limestones require particular attention because of the frequently developed solution features (sinkholes, caverns). Although faults are not common in this area, foundation problems may occur, especially in the area of the Williamsport fault in the northwest corner of the mapped area. The presence of cleavage poses no significant problems, except where the bedrock is exposed to weathering (especially in the Bloomsburg Formation and the lower part of the Keyser Formation). In general, the presence of cleavage in borrow pits (as in Mosquito Valley) aids in the removal of material.

Possible uses—These evaluations reflect both current uses and potential uses determined from the general characteristics of the unit. The shales and some siltstones are sources for the most common use, local fill and road metal. The limestones are extensively used for road foundations and as aggregate. However, their use in concrete for roads has become severely limited because of their low skid resistance rating as established by Pennsylvania Department of Transportation Bulletin 13. Formations that are likely to rate high for anti-skid resistance are the Bald Eagle, Tuscarora, Brallier, and the sandier parts of the Juniata. The Bald Eagle and Tuscarora are also good sources of riprap.

Groundwater—The groundwater data are taken from a detailed report in preparation by O. B. Lloyd, Jr., and L. D. Carswell of the U. S. Geological Survey, Ground Water Branch.

Within the mapped area, 225 domestic wells were examined in detail. Despite the wide range of lithic types among the 16 formations penetrated by these wells, most of the median depths of the wells were between 100 and 150 feet (30 and 46 m), and the majority of well depths ranged between 50 and 350 feet (15 and 107 m) (Table 2). Although the wells in the Quaternary deposits have lesser depths, they are fairly deep, which is not surprising considering the great thicknesses of some of these surficial deposits. The median yields of all the wells range from 6 to 26 gpm (0.4 to 1.6 l/s); the higher yields are in the surficial deposits (Quaternary) and in the carbonate rocks (Mifflintown, Wills Creek, Tonoloway, Keyser, Old Port, and Onondaga Formations). The Keyser Formation is exceptional—it has a median yield of 200 gpm (13 l/s). Much of the water from these wells is chemically nearly neutral; the mean pH ranges from 6.6 to 7.6. The principal exceptions were in wells from the Bald Eagle and Juniata Formations, which are somewhat acidic and low in hardness. The most alkaline water came from wells in the Rose Hill, Marcellus, and Keyser Formations. The formations yielding the hardest water are the Tonoloway and Rose Hill.

Table 2. *Groundwater Data for 225 Domestic Wells*

Formation penetrated	No. of wells	Well depth, in feet: median (range)	Water level, depth to (feet): median (range)	Well yield, in gpm: median (range)	Specific capacity*: mean	pH: mean	Hardness, ppt:mean
Quaternary	40	45(11–102)	12(2–70)	26(5–525)	3.20	5.7	4
Trimmers Rock	8	110(75–310)	22(0–165)	6(1–183)	.07	- - -	5**
Harrell	4	142(100–150)	22(1–93)	5(1–15)	.07	- - -	- - -
Tully	11	135(50–335)	35(12–110)	10(2–36)	.23	- - -	- - -
Mahantango	35	140(52–455)	20(0–200)	12(2–42)	.30	7.0	4.5
Marcellus	10	108(50–350)	34(2–90)	7(2–24)	.12	7.6**	6**
Onondaga	5	134(73–350)	63(0–100)	20(6–20)	.08**	- - -	- - -
Old Port	23	103(5–548)	40(10–86)	20(2–165)	.53	7.0	7
Keyser	8	167(63–464)	20(1–60)	200(8–380)	5.79	7.5**	6
Tonoloway	21	122(52–575)	35(2–124)	25(8–323)	1.60	7.0	11
Wills Creek	13	90(40–148)	23(2–65)	24(5–100)	1.27	6.6**	6**
Bloomsburg	21	111(55–500)	25(7–100)	15(3–140)	.39	6.9**	8**
Mifflintown	5	200(171–215)	50(28–100)	20(12–30)	.12	- - -	- - -
Rose Hill	8	176(100–415)	12(0–56)	11(3–150)	.16	7.6**	9**
Tuscarora	0	- - -	- - -	- - -	- - -	- - -	- - -
Juniata	4	164(48–250)	45(4–81)	20(18–30)	.23**	5.5**	2**
Bald Eagle	9	160(100–400)	55(0–230)	10(2–20)	.09	6.5**	1**

*Specific capacity is the amount of water produced by a well in a given time interval, per unit length of drawdown, and is expressed in this table as gallons per minute per 50 feet of drawdown. Specific capacity is generally a better measure than yield is of the discharge capabilities, because yield is dependent upon the depth of the well and the depth to the water level.

**Data are from less than four wells.

The nondomestic wells in this area are generally drilled deeper than the domestic wells in order to obtain greater yields. Both the yields and the specific capacities are significantly higher than for the domestic supplies. With respect to hardness and pH, though, the two types of wells are similar.

SPECIFIC AREA COMMENTS

The Montoursville, Muncy, and Hughesville quadrangles can be divided into four environmentally different areas, each with specific geologic and topographic parameters that influence the activities of man. These areas are, from north to south, the Susquehanna River valley, Bald Eagle Mountain (including North White Deer Ridge), White Deer Valley (including Delaware Valley), and the Muncy Hills.

SUSQUEHANNA RIVER VALLEY

The Susquehanna River crosses the northern part of the mapped area, turns southward around Bald Eagle Mountain, passes north and west of the Muncy Hills, and exits across the southern margin. Rocks of considerable diversity underlie the valley, but most of the bedrock is overlain by thick deposits of alluvial sands and gravels. Thus, environmental concerns relate more to the surficial materials than to the bedrock. Current and potential uses in this valley include agricultural (the dominant current use), residential, industrial, and extractive (sand and gravel quarries). Recreation is confined mostly to the river itself and a number of vacation dwellings occur along the shore. The primary hazard is from flooding, but both Williamsport and South Williamsport have built levees, which were sufficient to protect these areas during Tropical Storm Agnes in 1972. Muncy, unprotected by levee, was badly flooded by this storm. Much of Montgomery is on sufficiently high ground to have escaped extensive damage. Industrial and residential development should be discouraged in areas outside the levees that are still subject to flooding—these areas are better suited for open-space use and recreation. A second hazard is local slumping in till deposits (Figure 19), particularly when they are water saturated. The extensive sand and gravel deposits provide the area with a large economic asset that is currently being exploited at only one location, south of Montoursville. The sands and gravels can also be utilized for groundwater—Muncy's water supply is totally drawn from wells in the gravels along Muncy Creek.

BALD EAGLE MOUNTAIN-NORTH WHITE DEER RIDGE

Bald Eagle Mountain and North White Deer Ridge comprise an area of high mountains and steep slopes. Almost all of this area is covered by varying thicknesses of boulder and stony colluvium, and by recessional mor-

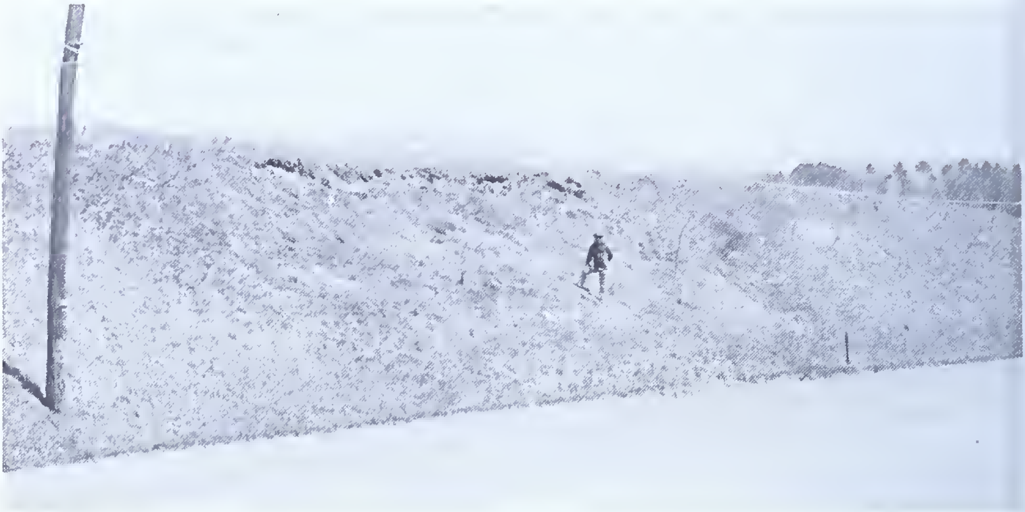

Figure 19. Engineering hazard in a 6-m- (20-ft-) high cut in glacial till along U. S. Route 220, 4 km (2.5 mi) east of Montoursville. The 10-m- (33-ft-) long scar in the slope is a result of recent slumping of the till onto the shoulder of the road.

aines along the lower southern slopes. Current and potential uses in this extensively forested area are primarily recreational, and much of the land belongs to the Tiadaghton State Forest. A moderate potential exists for low- to medium-grade lumber. The headwater area of Hagermans Run provides a water supply for Williamsport. Three hazards are prevalent in this area. Slope stability is a significant problem on the steep mountain slopes underlain by boulder and stony colluvium derived from the Tuscarora, Juniata, and Bald Eagle Formations. The hummocky surface suggests that local mass movement is possible, particularly when the colluvium is water saturated. Another aspect of this hazard occurs where man-made excavations extend to bedrock, as in places east of South Williamsport (Figure 20). The bedrock, if fresh, is quite solid, but the colluvium is both washed down by rainfall and undergoes slumping. This downslope movement of material requires both fences and periodic removal of material from the foot of the slope (Figure 20). A second hazard is pollution of the watersheds of Hagermans Run; because of the very limited development in this area, it is not serious at present. The third hazard consists of rockfalls from fractured Tuscarora and Juniata exposures in steep man-made cuts, as along highways (Figure 21). Improved designs of cuts, as well as heavy fences, do much to alleviate this hazard.

WHITE DEER VALLEY

The northern limit of this area is the foot of the steep slopes of Bald Eagle Mountain and North White Deer Ridge (the northern limit of the Delaware Valley is the Muncy Hills). The surface of most of the valley is covered by

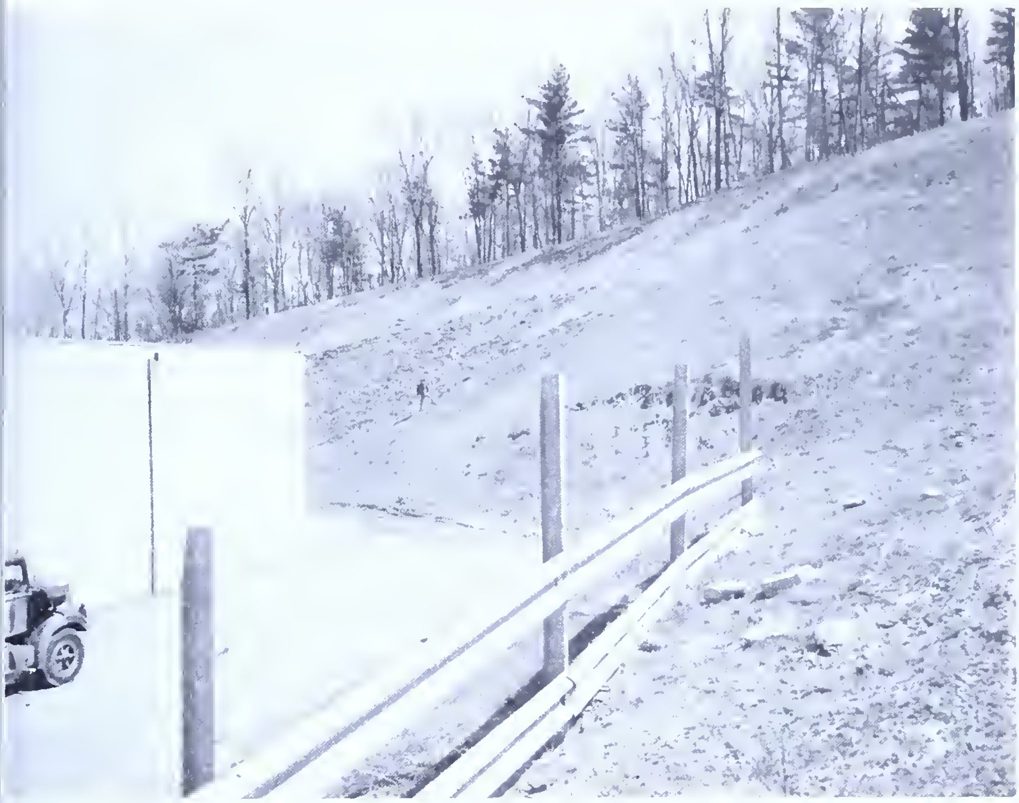

Figure 20. Engineering hazard in an excavation into the base of the north slope of Bald Eagle Mountain, 1 km (0.6 mi) east of Hagermans Run. Vertical beds of the Rose Hill Formation, exposed in the lower part of the cut, are fresh and stable. Overlying the bedrock is up to 8 m (26 ft) of boulder colluvium (figure is standing on contact). The fence in the foreground serves to catch boulders rolling down the steep slope. The pebble and mud mixture is continually washed down onto the paved area, both by surface traction and by slumping, and must be periodically removed.

glacial till, and by colluvium and regolith, which are present in lesser amounts. Current and potential land use includes agricultural (the primary current use), residential (some recent increase, but still relatively minor), industrial (no use at present), recreational (a sizable tract of Pennsylvania State Game Lands exists in the center of the valley), and governmental (another sizable tract is used by the U. S. Penitentiary as a prison camp, on which a large landfill for Lycoming County was recently constructed). Because of the low to moderate slopes and relative stability of the surficial material, there should be no particular foundation or cut-slope problems (except in local areas where glacial till may exceed 3 m (10 ft) in thickness). Terrain underlain by the Tonoloway and Keyser Formations probably would present significant problems; sinkholes often develop on this unit, and foundation conditions for large structures should be carefully examined

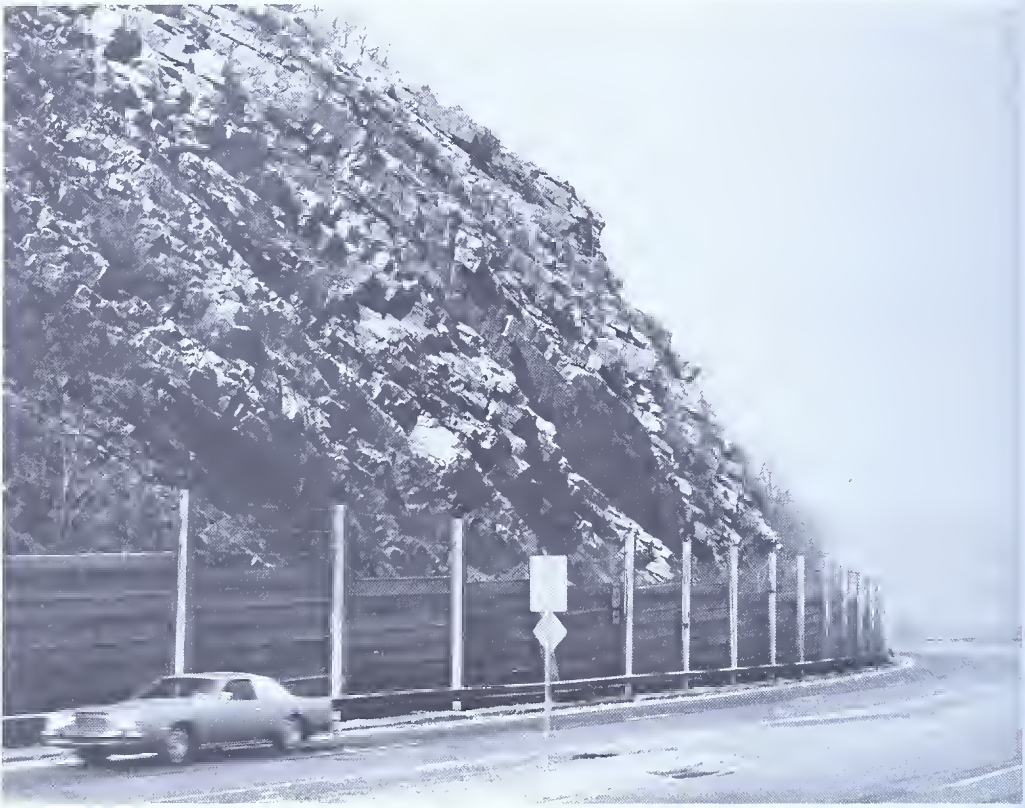

Figure 21. Engineering hazard in a roadcut in the Tuscarora and Juniata Formations (contact passes through the base of the road sign behind the automobile) along U. S. Route 15, 4 km (2.5 mi) east of South Williamsport. Continuous rockfall of fractured sandstone beds necessitated the erection of a retaining fence along the shoulder to keep rocks off the road. The city of Williamsport is in the valley in the distance.

to determine presence of sound rock. The Sink is a particularly large example of coalesced sinkholes.

MUNCY HILLS

The Muncy Hills area extends eastward from Montgomery across the southern portion of the Muncy and Hughesville quadrangles, and northward, where it includes all the terrain east of Hughesville. This area consists of hills deeply incised by numerous small streams and a larger stream, Little Muncy Creek. The surface of most of the area is covered by variable thicknesses of regolith on hilltops and colluviated bedrock on the hillsides. Current and potential uses are agricultural and residential. Approximately half of the area, on hilltops, the gentler slopes, and in the few floodplains, is extensively farmed, and the remainder is given over to forest. The extensive farming restricts recreational use of the land. Industrial use is quite limited because of the hilly terrain. The natural slopes are generally stable, but may be hazardous for even light structures on the colluvium. The only other significant hazard is the potential of flooding in the narrow stream valleys.

ECONOMIC RESOURCES

Stone (coarse aggregate), and sand and gravel are the principal economic mineral resources in the Muncy-Montoursville area. These and other potential materials, such as chemical grade limestone, agricultural lime, clay and shale, rottenstone (tripoli), dimension stone (riprap), uranium, and oil and gas, are evaluated with respect to geologic setting, composition, utility, and extractability. Because of progressive residential and urban development and a consequent increase in zoning ordinances, deposits of significant potential value are described so that planners and local officials will be aware of their presence.

COARSE AGGREGATE

Coarse aggregate, as specified by the Pennsylvania Department of Transportation (PennDOT), includes crushed stone, gravel, and slag. Sources of gravel are abundant in these three quadrangles; the potential for crushed stone, although sizable, is not as large.

Currently, Type A stone, which must be prepared from a tough, durable rock free of closely spaced partings (such as laminations, cleavage, or fractures), and consists of equidimensional fragments, is being quarried from the Silurian Tonoloway and Keyser Formations at the Lime Bluff quarry northeast of Muncy. The product is overwhelmingly limestone, and contains only minor amounts of magnesian limestone or dolomite. These two stratigraphic units extend eastward from Williamsport to Lime Bluff, and thence west-southwestward through Muncy, and north to Montgomery to Elimsport just west of the mapped area before trending eastward again, just south of the southern edge of the quadrangles. These formations underlie a considerable area, but the bedrock is overlain by thick surficial deposits along much of its length. Therefore, although a large quantity of rock is present, it would be uneconomical to attempt to mine much of it. Only the Lime Bluff quarry is now active. Numerous other quarries have been opened and subsequently abandoned, especially in Lymehurst; there have also been a few in Fairfield Township, at Chippewa northwest of Lime Bluff, and west of Spring Creek in the southwest corner of the mapped area.

The stone produced from the Lime Bluff quarry is used primarily for road metal, concrete, macadam, and fill. Although the angularity of this aggregate is excellent for concrete strength, the low skid-resistance level (SRL), as established by PennDOT Bulletin 13, will probably limit its use as highway concrete in the future. Other stratigraphic units that have potential as coarse aggregate are the Bald Eagle and Tuscarora Formations and the upper part of the Juniata Formation. These units would yield excellent coarse aggregate having a fairly high SRL, but they are so siliceous that the cost of crushing and processing may be prohibitive. Despite the fact that the Trimmers Rock Formation contains a considerable amount of shale, it tends to be siliceous, and the unweathered rock would probably yield good to excellent Type A aggregate. If so, it would probably have a high SRL and would be relatively easy to process. Thus, it would have a distinct use advantage over the currently quarried limestones. The other stratigraphic units in this area are too shaly to provide good to excellent aggregate.

The other large source of coarse aggregate within these quadrangles is the Quaternary alluvial deposits in the Susquehanna River valley and its major tributaries (Muncy and Loyalsock Creeks) (see Plate 2 for the areal extent of these surficial deposits). Only one sand and gravel pit is currently active in these deposits, being operated south of Montoursville by the Lycoming Silica Sand Company. The alluvium consists of a variable mixture of silt, sand, and gravel. Fourteen samples of alluvium were collected from various localities (Figure 22, numbers 1 through 14) and subjected to a sieve analysis (Figure 23). Of these samples, slightly more than half contain sufficient gravel to be suitable for 2, 2A, or 2B aggregate (Pennsylvania Department of Transportation numbers) with a minimum of sand separation. Most of the gravels are quite clean, having only a trace of silt and clay in them (Figure 24A). These deposits occur south of Montoursville (in the currently active quarry) and in the vicinity of Muncy. Much of the remainder of the Susquehanna Valley exposes only fine sandy loam at the surface (as seen in the remainder of the analyses), but these samples were taken from 1- to 2-m- (3- to 7-ft-) thick surface exposures. The absence of gravel at the surface does not preclude its presence at depth, but only auger tests would be able to demonstrate this.

The gravels consist generally of well-rounded to flat pebbles, not infrequently containing as much as 5 to 10 percent cobbles, and occasionally scattered boulders, predominantly of gray sandstones but also containing lesser admixtures of both red and gray siltstones. The finer gravel tends to have a greater proportion of red siltstones, particularly in the Muncy Creek vicinity. The alluvial deposits range in thickness from 8 to 25 m (25 to 80 ft), and continue for the length of the Susquehanna Valley, which varies in width from 1 to 3 km (0.6 to 1.9 mi).

Coarse aggregate also occurs in small deposits of ice-contact stratified drift (Figure 22, numbers 15-19). Analysis of two samples (numbers 15 and 17) indicates that these deposits are more than 65 percent gravel, and contain lesser amounts of cobbles (5 to 20 percent) and boulders (1 to 2 percent). The matrix is clean sand (1 percent silt and clay) which is medium grained (mean size).

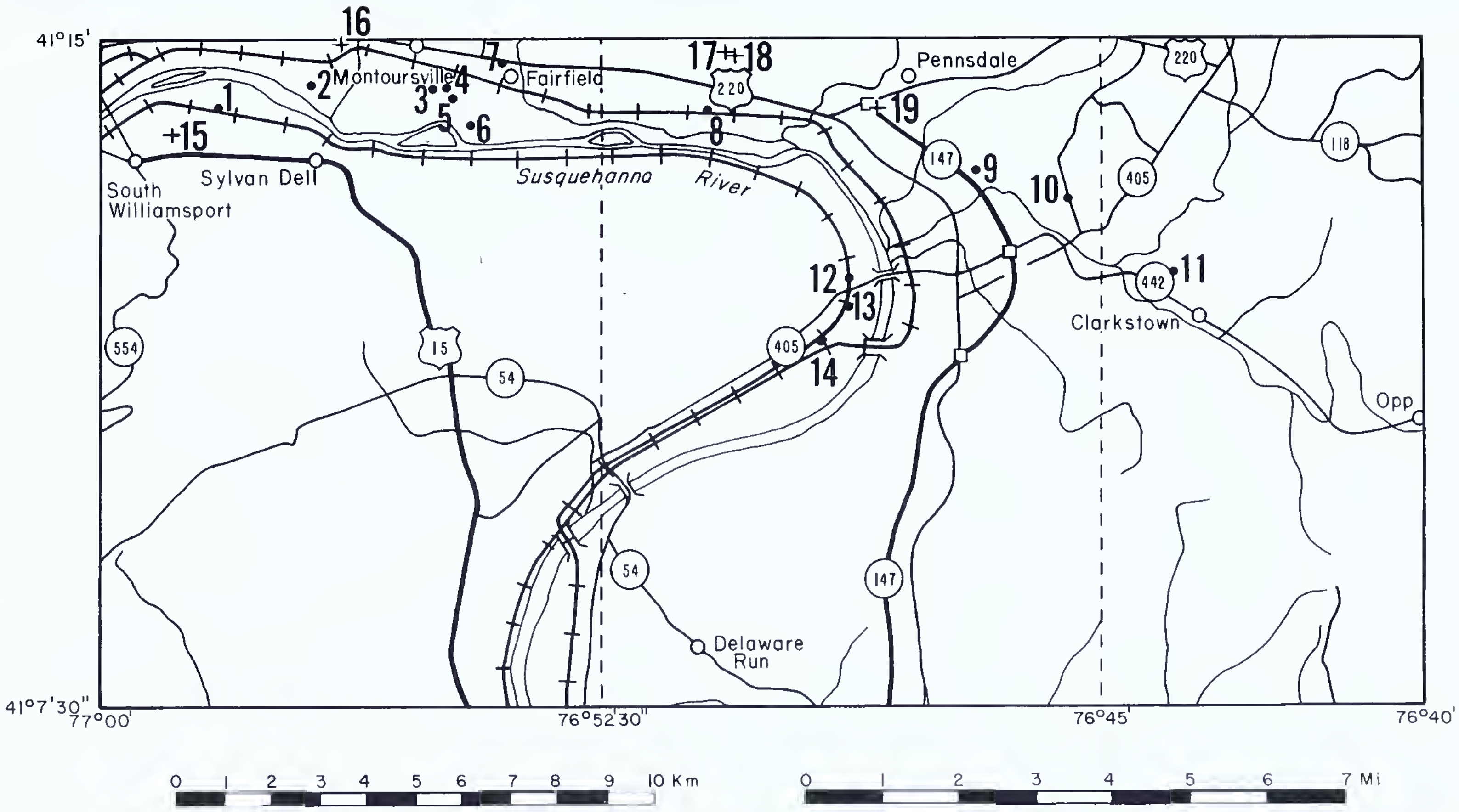

Figure 22. Location map for collected and analyzed samples of surficial material. Dots represent alluvial samples; crosses represent glacial-drift samples.

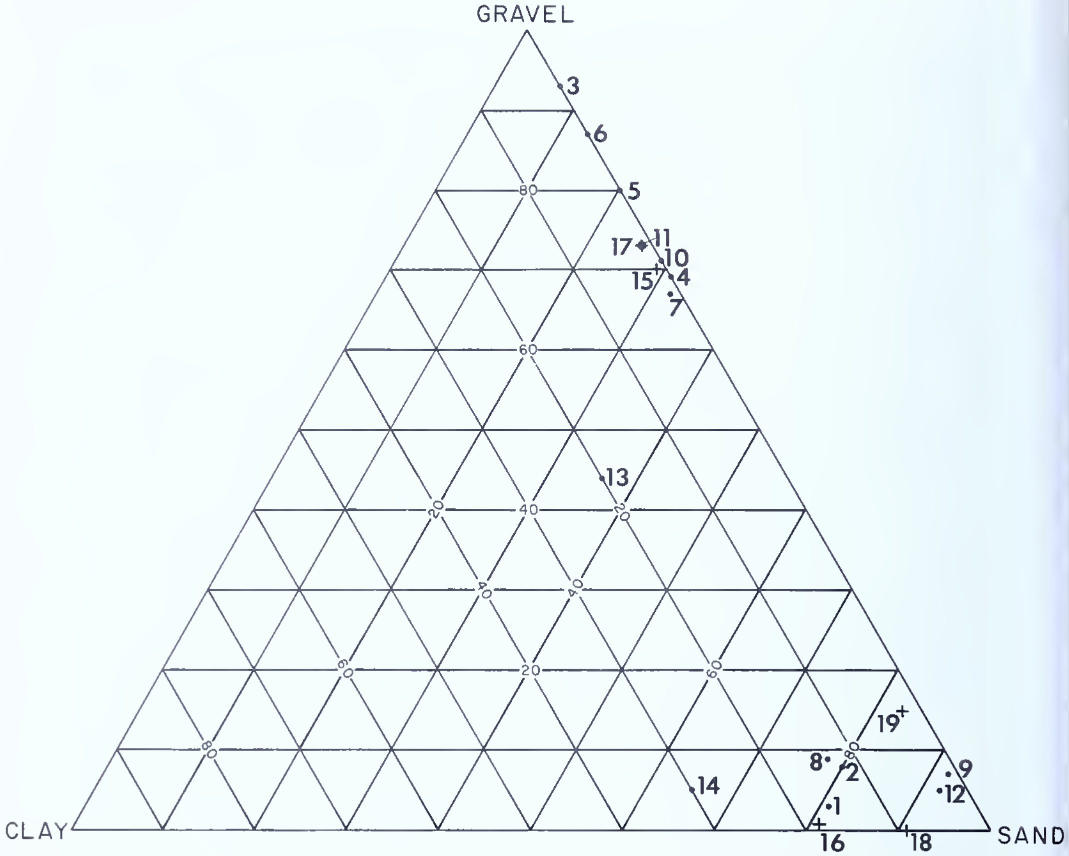

Figure 23. Ternary diagram illustrating relative proportions of gravel, sand, and silt/clay in each sample of surficial material. Dots represent alluvial samples; crosses represent glacial-drift samples.

FINE AGGREGATE

Fine aggregate consists of hard, durable grains of sand size (0.062 to 2 mm); it is clean, and free of clay and vegetable substances (Pennsylvania Department of Transportation specifications). The principal sources for fine aggregate in this area are the alluvial deposits in the Susquehanna Valley (primarily) and the stratified-drift occurrences (to a lesser extent). In both types of deposits, sand is found both as a matrix in gravel bars, and in gravel-free bodies. The sand in the gravel bars (Figure 23) is generally coarser; it has a mean grain size of medium (ranging from 0.27 to 0.45 mm), and contains less than 10 percent fine and virtually no very fine sized grains. In the gravel-free bodies (Figure 23), the mean grain size is usually fine to very fine (ranging from 0.10 to 0.18 mm); these deposits contain 5 to 15 percent silt and mud (maximum 30 percent). The sorting in these finer grained deposits is much better than in the gravel deposits; 70 or more percent of the grains are within one ϕ (between twice and one-half) of the mean size.

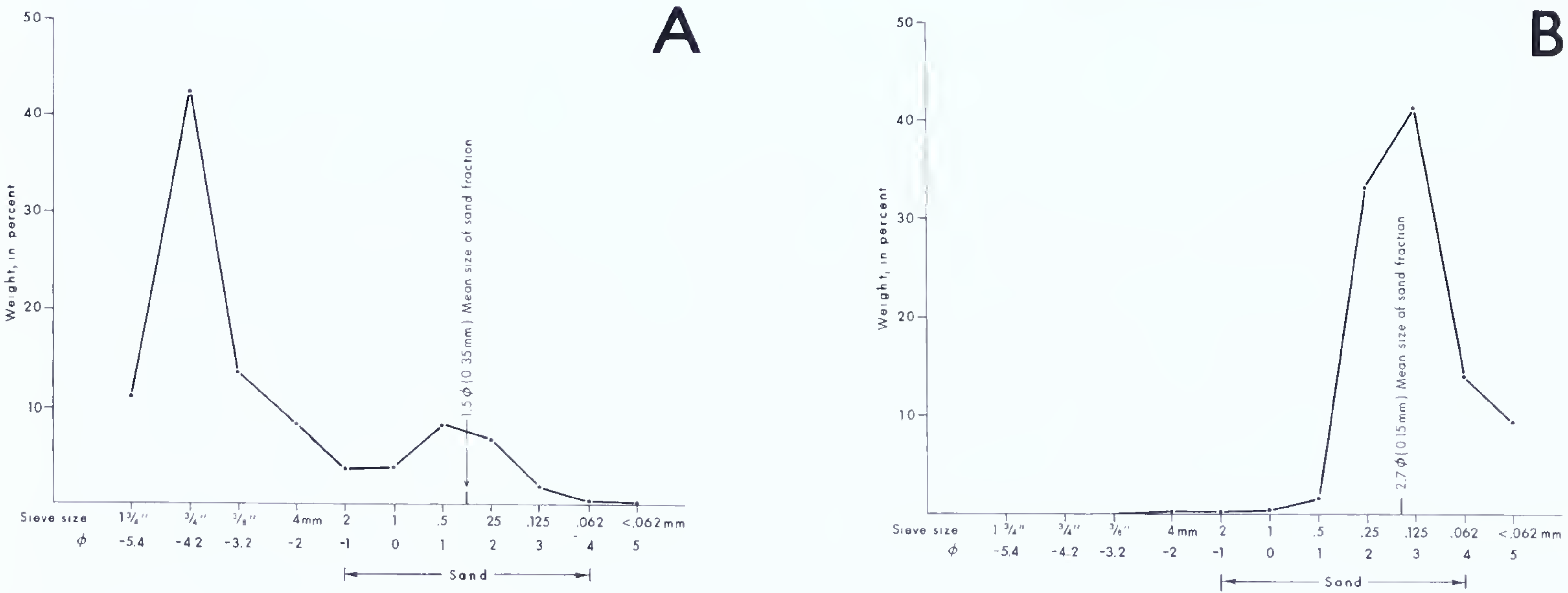

Figure 24. Seive analyses of two representative samples of surficial material. A. Alluvial gravel from the Susquehanna River floodplain southeast of Montoursville (sample 5 in Figures 22 and 23). The large percentage of gravel is characteristic of much of the alluvium in this valley. With the gravel fraction removed, the sand has a fair sorting and is medium grained, having a mean grain size of 1.5 ϕ (0.35 mm). B. Ice-contact stratified drift north of Susquehanna floodplain along U. S. Route 220 (sample 18 in Figures 22 and 23). Most of this large drift body is without a gravel fraction (except on the west side—see sample 17, Figure 23), and the sand is fairly well sorted and fine grained, having a mean grain size of 2.7 ϕ (0.15 mm).

CHEMICAL GRADE LIMESTONE

Chemical grade limestone has a number of special uses: fluxstone for steel manufacturing, glass manufacturing, smokestack scrubbers, paint filler, and lime production are the more common ones. In general, the calcium carbonate content for these uses should exceed 85 to 90 percent and the silica content should be correspondingly low. Two formations were sampled for chemical analysis—the uppermost Tonoloway and the Keyser. This interval was sampled in three localities: at the Lime Bluff quarry northeast of Muncy; at the Allenwood quarry in the southwest corner of the Allenwood Prison Camp; and south of the mapped area, at the Limestoneville quarry east of Milton. Samples from these three localities were part of a collection program extending from Jersey Shore to the west to Berwick to the southeast (Faill, 1976).

Eight samples were collected from the purest appearing beds in the Lime Bluff quarry, four from the top of the Tonoloway Formation, and four from Keyser beds above the argillaceous cobbly lower portion (Figure 25 and Table 3). The four Tonoloway samples were taken from an interval of thick-bedded birdseye calcilutite overlying the typical platy beds. All four samples exhibit $CaCO_3$ content greater than 95 percent, which would make this 8.9-m- (29.2-ft-) thick interval excellent as a chemical grade lime. The much lower $CaCO_3$ values for the Keyser samples would preclude its use as high-calcium lime.

Six samples were collected from the uppermost part of the Tonoloway at the Allenwood quarry (Figure 25 and Table 4). All six samples, encompassing a stratigraphic interval of 14.1 m (46.3 ft), yielded $CaCO_3$ contents between 93 and 95 percent.

Fifteen samples were collected from the upper part of the Tonoloway and the lower part of the Keyser in the quarry at Limestoneville (Figure 25 and Table 5). This group of samples is considerably more extensive than the other two groups, spanning 30.1 m (98.8 ft) of the upper Tonoloway and 14.4 m (47.2 ft) of the lower part of the Keyser Formation, and revealing two additional features. None of the limestone in the lower 10 m (33 ft) of the Keyser at both Lime Bluff and Limestoneville contains $CaCO_3$ above 85 percent. Whereas a 3.5-m (11.5-ft) interval above at Lime Bluff is 87 percent $CaCO_3$, the corresponding interval at Limestoneville is more than 91 percent. However, this sequence may be too thin to exploit economically. The other feature is the high $CaCO_3$ content of the platy-bedded portion of the Tonoloway Formation that underlies the birdseye calcilutite. This signifies that a large portion of the Tonoloway may be suitable for chemical grade lime. This part of the formation was not sampled at Lime Bluff, but the lithic similarity of the beds there suggests that they may also contain high values of $CaCO_3$.

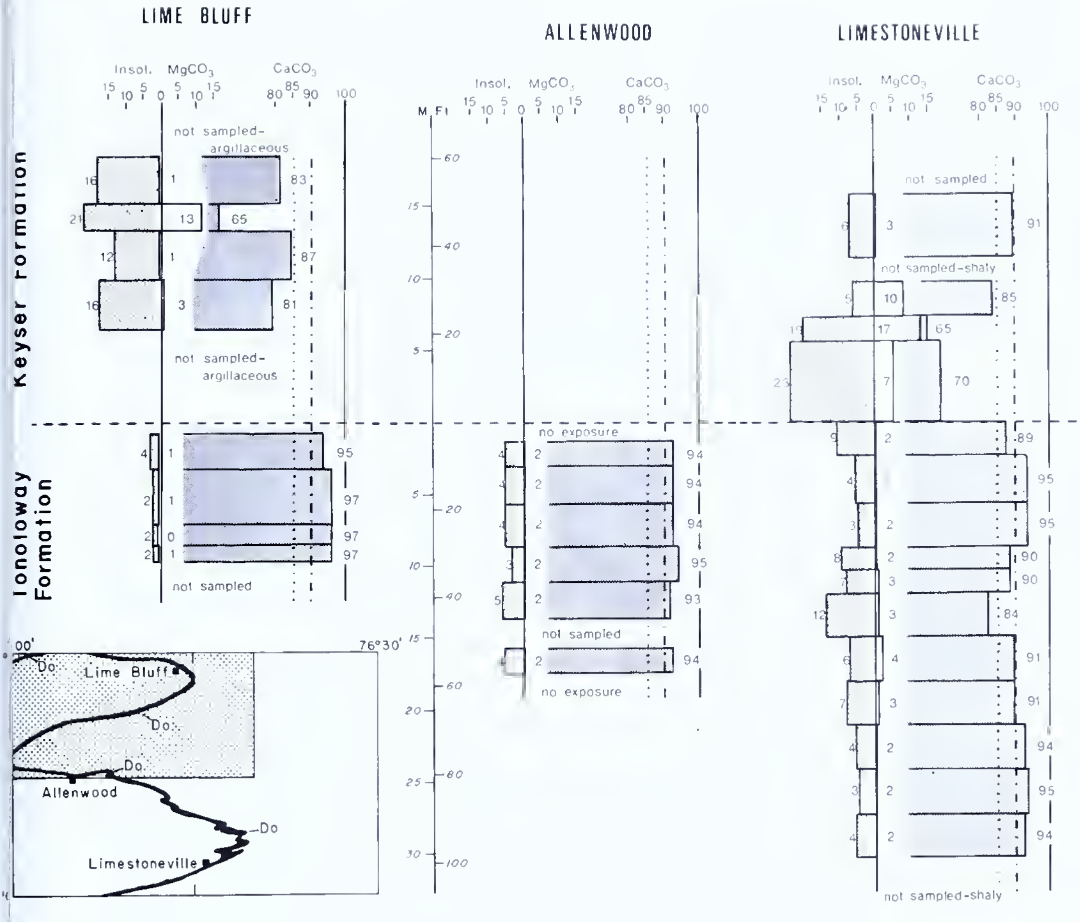

Figure 25. Correlated columns showing chemical analyses and thicknesses of sampled limestones from three quarries in or near the mapped area. Diagonal line pattern—$CaCO_3$; outlined white area—$MgCO_3$; stipple pattern—insoluble residue; numbers—percent composition, by weight. The zero for the $CaCO_3$ scale does not coincide with the zero for the $MgCO_3$ and insoluble-residue scales.

This same stratigraphic interval was sampled west of this area, at Jersey Shore (Faill and others, 1977a). The birdseye calcilutite is not present there; the cobbly lower Keyser directly overlies the laminated and platy beds of the Tonoloway Formation, and the $CaCO_3$ contents range from 69 to 86 percent. The high-calcium zone apparently terminates somewhere between Lime Bluff and Jersey Shore. Scattered quarries exist between Lime Bluff and Lymehurst (west of Montoursville), but samples have not been collected from any of these exposures. West from Lymehurst to Jersey Shore, this stratigraphic interval is nowhere exposed, being overlain by thick alluvi-

Table 3. *Chemical Analyses of Limestones from the Lime Bluff Quarry*

Location:
Lat. 41°14′03″N; Long. 76°45′56″W.
Muncy, Pa., 7-1/2-minute quadrangle.
3.6 km (2.3 mi) northeast of Muncy, Pa.

Eight samples were gathered for chemical analysis from the northeast-dipping beds at the northwest end of the quarry (northern pit).

Each sample comprises equal-sized fresh fragments (weathered surfaces removed) collected at stratigraphic intervals of 15 to 25 cm (6 to 10 in.). Chemical analyses were performed by the U.S. Bureau of Mines.

Samples 1-4 are from the uppermost Tonoloway Formation. Samples 5-8 are from the lower part of the Keyser Formation. The samples were consecutive except for a 7.1-m (23.4-ft) interval between samples 4 and 5.

Sample 8: Calcisiltite, dark-gray, medium- to very thick bedded, homogeneous, fossiliferous.
Sample 7: Calcisiltite, medium- to yellowish-gray, single bed, mottled, argillaceous, fossiliferous.
Sample 6: Calcisiltite, homogeneous, medium-dark-gray, containing bed-parallel stylolites.
Sample 5: Calcisiltite, medium- to medium-dark-gray, very thick bedded, containing bed-parallel stylolites and shale partings.
Not sampled: Calcisiltite and calcarenite, cobbly, medium-light- to medium-gray, cherty, argillaceous.
Tonoloway-Keyser contact.
Sample 4: Calcisiltite and calcilutite, homogeneous, medium-gray, thin- to medium-bedded, containing bed-parallel stylolites, laminated in lower part.
Sample 3: Calcilutite and fine calcisiltite, birdseye, medium-gray, medium- to thick-bedded.
Sample 2: Calcilutite and fine calcisiltite, dense birdseye, medium-gray, single bed having one bed-parallel stylolite.
Sample 1: Fine calcisiltite, dense birdseye, medium-dark- to dark-gray, single bed having two bed-parallel stylolites.
Not sampled: Fine calcisiltite, medium-dark- to dark-gray, thin- to medium-bedded, laminated, containing numerous bed-parallel stylolites, and clay accumulations on bedding surfaces.

Sample no.	1	2	3	4	5	6	7	8
Thickness, m (ft)	1.1 (3.6)	1.5 (4.9)	3.8 (12.3)	2.5 (8.2)	3.6 (11.7)	3.5 (11.5)	1.7 (5.6)	3.6 (11.8)
SiO_2	1.30	1.17	1.43	2.00	8.80	11.73	15.91	14.06
Al_2O_3	.09	.06	.14	.35	1.14	.45	3.83	.77
Fe_2O_3	.19	.10	.10	.13	.06	.05	.20	.06
MgO	.54	.15	.26	.25	1.58	.57	6.42	.31
CaO	54.6	55.4	55.5	53.7	45.0	47.0	38.9	46.6
Na_2O	.11	.13	.08	.07	.05	.02	.03	.03
K_2O	.34	.04	.13	.03	.15	.15	.22	.13
P_2O_5	.09	.02	.07	.01	.10	.11	.12	.06
Loss on ignition	43.16	42.98	42.98	42.16	43.71	39.13	34.50	37.58
Total S, as SO_3	.01	.04	.08	.03	.03	.01	.29	.54
Sulfate S, as SO_3	.01	.00	.00	.00	.01	.03	.03	.02
Sum	100.44	100.09	100.77	98.73	100.63	99.25	100.45	100.16
Insol. res.	2.03	2.23	2.44	4.37	15.53	11.67	20.77	16.49
$MgCO_3$*	1.12	0.31	0.53	0.52	3.33	1.23	12.73	0.65
$CaCO_3$	96.85	97.46	97.03	95.12	81.01	86.71	65.84	82.92
Insol. res.	2.03	2.23	2.44	4.36	15.66	12.06	21.43	16.44

* Assuming all L.O.I. is CO_2, recalculated to 100 percent.

Table 4. *Chemical Analyses of Limestones from the Allenwood Quarry*

Location:
Lat. 41°07′20″N; Long. 76°57′19″W.
Allenwood, Pa., 7-1/2-minute quadrangle.
In southwest corner of Allenwood Prison Camp, 5.0 km (3.1 mi) west-northwest of Allenwood, Pa.

Six samples were gathered for chemical analysis from the nearly horizontal beds along the south wall of the quarry.

Each sample comprises equal-sized fresh fragments (weathered surfaces removed) collected at stratigraphic intervals of 15 to 25 cm (6 to 10 in.). Chemical analyses were performed by the U.S. Bureau of Mines.

All samples were taken from the upper part of the Tonoloway Formation. The samples are consecutive except for a 2-m (6.7-ft) interval between samples 1 and 2.

Not sampled: Fossiliferous limestone at top of east wall.

Sample 6: Limestone, medium- to thick-bedded.

Sample 5: Limestone, thin-bedded in upper 1.2 m (3.9 ft), thick-bedded in lower part.

Sample 4: Calcisiltite, medium-light- to medium-dark-gray, very thick bedded, laminated (1 to 6 cm, or 0.6 to 2.4 in.).

Sample 3: Alternating fine calcisiltite, medium-gray, laminated (1.5 to 5 cm, or 0.6 to 2.0 in.), having bed-parallel clay partings; and calcilutite, medium-gray, not laminated, having numerous bed-parallel stylolites.

Sample 2: Fine calcisiltite, medium-gray, thick- to very thick bedded, containing laminae (1 to 5 cm, or 0.6 to 2.0 in.) separated by very thin, finely laminated layers; has numerous bed-parallel stylolites.

Not sampled: Calcisiltite, finely laminated in upper part, coarsely laminated in lower part.

Sample 1: Fine calcisiltite, medium-gray, thick- to very thick bedded, coarsely laminated.

Sample no.	1	2	3	4	5	6
Thickness, m (ft)	1.8 (5.9)	2.5 (8.2)	2.5 (8.2)	2.9 (9.4)	2.7 (9.0)	1.7 (5.7)
SiO_2	4.1	4.2	2.2	3.4	3.7	3.0
Al_2O_3	0.4	0.6	0.3	0.5	0.5	0.4
Fe_2O_3	0.31	0.60	0.91	0.18	0.23	0.98
MgO	1.0	0.9	1.0	1.1	1.1	1.1
CaO	52.9	51.7	51.0	51.7	52.0	52.1
Na_2O	0.02	0.01	0.02	0.01	0.02	0.02
K_2O	0.13	0.16	0.11	0.16	0.19	0.13
P_2O_5	0.01	0.02	0.02	0.02	0.02	0.02
Loss on ignition	41.0	41.7	41.6	41.4	42.1	42.0
Total S, as SO_3	0.10	0.06	0.09	0.08	0.08	0.11
Sulfate S, as SO_3	0.10	0.06	0.07	0.08	0.08	0.07
Sum	100.07	100.01	97.32	98.63	100.02	99.93
Insol. res.	4.2	4.7	2.5	3.4	4.1	3.5
$MgCO_3$*	2.07	1.90	2.19	2.35	2.32	2.33
$CaCO_3$	93.60	93.34	95.20	94.15	93.55	94.12
Insol. res.	4.33	4.75	2.61	3.50	4.13	3.55

* Assuming all L.O.I is CO_2, recalculated to 100 percent.

Table 5. *Chemical Analyses of Limestones from the Limestoneville Quarry*

Location:
Lat. 41°01′50″N; Long. 76°43′54″W.
Washingtonville, Pa., 7-1/2-minute quadrangle.
0.6 km (0.4 mi) south of Pa. Route 254, 5.1 km (3.1 mi) west of Washingtonville, 10.4 km (6.4 mi) east of Milton, Pa.

Fifteen samples were gathered for chemical analysis from the moderately south dipping beds at the west end of the quarry, from the second and third benches from the bottom. Each sample comprises equal-sized fresh fragments (weathered surfaces removed) collected at stratigraphic intervals of 15 to 25 cm (6 to 10 in.). Chemical analyses were done by the U.S. Bureau of Mines.

Samples 1-8 are from the upper part of the laminated, platy Tonoloway Formation, samples 9-11 from the birdseye limestone in the uppermost Tonoloway, and samples 12-15 from the lower part of the Keyser Formation. The samples are consecutive, except for a 1.5-m-(4.9-ft-) thick interval between units 14 and 15, which contained several clay seams.

Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Thickness, m (ft)	3.1 (10)	3.1 (10)	3.1 (10)	3.1 (10)	3.1 (10)	3.1 (10)	1.5 (5)	1.5 (5)	3.4 (11.2)	3.0 (9.8)	2.3 (7.6)	5.6 (18.4)	1.8 (5.9)	2.5 (8.2)	4.5 (14.8)
SiO_2	2.7	2.4	2.7	4.1	3.6	8.3	5.5	5.8	2.3	2.8	6.0	15.6	14.0	4.2	5.1
Al_2O_3	0.6	0.4	0.5	1.1	0.9	1.9	1.1	1.2	0.5	0.7	0.4	3.1	1.5	0.7	0.7
Fe_2O_3	0.35	0.18	0.45	0.32	0.25	0.56	0.35	0.37	0.32	0.24	0.25	1.58	0.58	0.36	0.27
MgO	1.0	0.8	1.0	1.2	1.8	1.7	1.3	1.0	0.9	0.7	0.8	3.3	8.5	4.7	1.2
CaO	50.0	54.0	52.5	51.1	51.0	48.2	51.0	49.8	53.0	52.0	50.6	40.0	39.0	48.2	50.5
Na_2O	0.03	0.02	0.02	0.03	0.05	0.04	0.03	0.02	0.01	0.01	0.02	0.07	0.24	0.07	0.03
K_2O	0.17	0.14	0.18	0.36	0.24	0.62	0.36	0.32	0.16	0.20	0.12	0.87	0.45	0.17	0.18
P_2O_5	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.05	0.04	0.04
Loss on ignition	44.4	42.0	42.0	41.0	41.7	38.3	40.0	40.9	42.8	42.5	40.9	33.8	36.6	41.5	41.7
Total S, as SO_3	0.09	0.08	0.11	0.12	0.09	0.14	0.07	0.10	0.08	0.09	0.12	1.62	0.44	0.23	0.20
Sulfate S, as SO_3	0.06	0.06	0.04	0.09	0.09	0.13	0.07	0.09	0.08	0.08	0.09	0.15	0.09	0.09	0.19
Sum	99.42	100.09	101.51	99.43	99.73	99.90	99.79	99.61	100.16	98.70	99.31	103.13	101.45	100.26	100.11
Insoluble residue	3.9	3.3	3.6	6.6	5.6	12.3	7.0	7.4	3.1	3.6	9.4	22.2	18.6	4.7	6.0
$MgCO_3$*	2.20	1.65	2.10	2.50	3.75	3.47	2.69	2.13	1.89	1.50	1.65	6.81	16.51	9.76	2.54
$CaCO_3$	93.71	95.00	94.25	90.86	90.64	84.07	90.13	90.35	95.00	94.83	89.08	70.49	64.66	85.41	91.37
Insoluble residue	4.09	3.35	3.65	6.64	5.62	12.46	7.18	7.52	3.11	3.68	9.27	22.70	18.83	4.83	6.08

* Assuming all L.O.I. is CO_2, recalculated to 100 percent.

um. A similar birdseye calcilutite ("Calico limestone") is present in the Altoona area 150 km (93 mi) to the southwest of this mapped area.

Minable reserves of limestone (within 30 m (100 ft) of the surface) containing more than 90 percent $CaCO_3$ along the Tonoloway-Keyser outcrop belt within the mapped area have been estimated to be at least 20 million tons (Figure 25). An additional 80 million tons is present south of the mapped area in the outcrop area north of the Susquehanna River (Faill, 1976). If the platy Tonoloway beds in the vicinity of Muncy contain as much $CaCO_3$ as the equivalent beds at Limestoneville, then the estimated reserves within the mapped area could be increased to 50 million tons. Inclusion of the limestones of 85 to 90 percent $CaCO_3$ would increase the reserve figures by approximately 50 percent.

No other limestones in the mapped area are of chemical grade. The Silurian Mifflintown Formation contains too many interbeds of shale and argillaceous limestone, and the Wills Creek Formation has shale and dolomite interbeds. The Devonian Onondaga Formation and the Tully Member of the Mahantango Formation are far too argillaceous for chemical grade use.

MAGNESIUM AND MAGNESIUM COMPOUNDS

Pure dolomite rock is used to produce magnesium metal, refractory magnesia, magnesium carbonate, and magnesium chloride. Impure dolomite rock is a source for coarse aggregate and agricultural dolomite. A few dolomitic beds occur in the Wills Creek and Keyser Formations, but none of these beds are sufficiently thick for the production of high magnesium products. The preponderance of limestone beds over dolomite beds probably precludes use as an agricultural dolomite.

IMPURE LIMESTONE

The two principal uses of impure limestone are Portland cement and agricultural limestone. The lower part of the Keyser Formation has been extensively utilized for agricultural lime, as evidenced by the large number of quarries that have burning kilns between Lymehurst and Lime Bluff and in the vicinity of Elimsport (southwest corner of the mapped area). However, all the quarries have ceased operation and production of lime, except for the Lime Bluff quarry. As for Portland cement, the Tonoloway is probably too pure, and the Keyser is too variable vertically for any economic production.

DIMENSION STONE

Dimension stone includes stone that is shaped or dressed for particular uses, as building stone, monumental stone, paving and curbing stone, and flagstone. Desirable attributes for dimension stone are durability, hardness, workability, strength, and porosity. Textures and colors are additional factors that are considered for specific uses.

In the nineteenth and early twentieth centuries, dimension stone was extensively used in the Williamsport-to-Muncy vicinity. Although some of this stone was brought in from other parts of the state, a local source was widely used—the float blocks on the north slope of Bald Eagle Mountain. The profusion of float blocks from the Tuscarora and Juniata Formations that exists on the slopes of Bald Eagle Mountain and North White Deer Ridge could provide stone that is very strong and durable, but it is difficult to work, and with the advent of concrete and other inexpensive building materials, it is uneconomical to process this stone. The limestones could be used for building and ornamental stone, but they do not have distinctive colors and textures that would make them competitive. Stones from the other stratigraphic units do not have the necessary strength, hardness, or durability.

OTHER STONE

This category includes all the stone that is produced and used without any sorting, washing, or dressing. The most common uses are for general fill, secondary road surfacing, and road shoulders. Sources are local borrow pits, most frequently in the Trimmers Rock, Marcellus, and Mahantango Formations. The silty shales common to all these units compact well without much dust production, and they also drain well. During the construction of the U. S. Route 220 bypass through Williamsport, a quarry was developed in Hagermans Run just east of the mapped area in the Bald Eagle Formation. The large boulders from this quarry were used for riprap for facing roadways and embankments against river currents.

GLASS SANDSTONE

The Old Port Formation is a lithically variable unit, containing limestone, sandstone, shale, and chert. The relative percentages of these constituents change from place to place. Of particular economic interest are the sandstones, which are very clean, well sorted, and friable, at least near the surface. Because of the friability of the sandstones, they have been quarried in the past as a source of sand, but they have been supplanted by the mining of the alluvial gravels and sands, particularly around Montoursville. The purity of these sandstones also makes them potentially suitable for glass manufacturing, although the limonite content may be excessive. Virtually all the grains consist of clear quartz, and they are cemented with calcite. The sandstone is very well sorted and has a mean grain size of 0.20 to 0.30 mm (fine to medium grained).

As good as the quality is, the thickness of the sandstone layers varies. In the Montoursville vicinity, the sandstone is probably 30 m (100 ft) or more thick, but to the east, around Pennsdale and Muncy, there seems to be only two 5-m- (16-ft-) thick sandstones separated by a black shale sequence. These two thin sandstones appear to extend southwestward from Muncy throughout White Deer Valley, although the thick and extensive till deposits mask much of the Old Port along its outcrop. The sandstone is again a single body (or nearly single), 30+ m (100+ ft) thick in a quarry by the railroad on the east side of the Susquehanna River, 0.2 km (0.1 mi) south of the boundary of the mapped area. How far to the east or west this thicker sandstone body extends is not known because of overlying thick till deposits.

CLAYS AND SHALES

Clays and shales are the raw material for a wide range of products: lightweight aggregate, bricks, tiles, pipes, refractory brick, and pottery and stoneware. Each of these requires particular characteristics from the raw shale or clay, and thus a shale that is excellent for one use may be unsuitable for another. Twenty-four shale samples were collected from within the mapped area and subjected to thorough tests (Table 6), including slow-firing tests (see Appendix 1). The formations sampled were: Rose Hill (nine samples), Bloomsburg (two samples), Wills Creek (one sample), Marcellus (three samples), Mahantango (four samples), Harrell (one sample), Trimmers Rock (two samples), and shale-chip colluvium (two samples).

Lightweight Aggregate

The primary requirements for lightweight aggregate are good expansion over a large firing range, and adequate strength. Of the formations tested, only three of the samples of the Mahantango shale yielded a positive bloating test. (A fourth sample was collected from the transition zone between the Marcellus and Mahantango Formations, and exhibited properties similar to the Marcellus.) The three samples behaved similarly, exhibiting good expansion (67 percent reduction in density from an average 2.00 to 0.66 gm/cc, or 125 to 41 lb/ft^3) with pore structure and some large pores (see Appendix 2). However, the firing range is rather restricted, extending only to 2100°F. Thus the Mahantango would be only marginal raw material for lightweight aggregate.

Structural Clay Products

For structural clay products, workability is probably the most important characteristic because many of these products are formed by the stiff-mud process, in which the clay must be extruded smoothly under pressure without laminations and other defects. All 24 samples possess short working properties, making them generally not suitable for structural-clay products

Table 6. *Ceramic Properties of Shales**

Sample number	Formation[1]	Latitude and longitude	Color[2]	Plasticity[3]	Water of plasticity, percent	Drying defects[4]	Drying shrinkage, percent	Dry strength[5]	pH	Effer-vescence with HCl[6]	Bloating test[7]	Vitrification temperature, degrees C
1	Qsr	41°14′47″N 76°40′10″W	b	s	17.1	n	2.5	f	6.8	n	n	1200–1250
2	Qsr	41°13′52″N 76°41′45″W	b	s	21.0	n	2.5	f	6.7	n	n	1200–1250
3	Dtr	41°10′32″N 76°41′45″W	g	s	17.0	n	2.5	p	8.0	s	n	1100–1150
4	Dtr	41°11′46″N 76°43′44″W	bk	s	15.7	n	0.0	p	7.5	s	n	1000–1050
5	Dh	41°11′50″N 76°43′50″W	bk	s	16.3	n	2.5	f	7.4	n	n	1000–1050
6	Dm	41°11′25″N 76°46′18″W	g	s	17.3	n	2.5	p	8.0	s	p	1100–1150
7	Dm	41°08′14″N 76°48′00″W	dk g	s	15.7	n	2.5	f	8.0	s	p	1100–1150
8	Dm	41°08′24″N 76°50′50″W	dk g	s	16.2	n	2.5	f	8.2	s	p	1100–1150
9	Dm	41°11′46″N 76°46′08″W	dk g	s	14.1	n	0.0	p	7.3	n	n	1050–1100
10	Dmr	41°11′49″N 76°46′13″W	bk	s	18.4	n	2.5	f	7.5	s	n	1100–1150
11	Dmr	41°14′46″N 76°51′03″W	bk	s	19.4	n	5.0	f	7.4	s	n	1100–1150
12	Dmr	41°08′22″N 76°59′34″W	bk	s	21.1	n	2.5	f	5.0	n	n	1100–1150
13	Sw	41°14′36″N 76°53′33″W	lt g	s	17.8	n	2.5	f	7.9	s	n	1100–1150
14	Sb	41°13′52″N 76°47′59″W	rb	s	16.3	n	2.5	f	7.2	n	n	1100–1150
15	Sb	41°14′15″N 76°51′38″W	rb	s	16.3	n	2.5	f	7.8	s	n	1100–1150
16	Sr	41°12′43″N 76°48′04″W	lt g	s	17.1	n	2.5	f	7.5	n	n	1150–1200
17	Sr[8]	41°05′54″N 76°53′26″W	g	s	16.2	n	2.5	f	8.2	s	n	1100–1150
18	Sr	41°05′51″N 76°53′23″W	g	s	16.0	n	2.5	f	8.1	s	n	1100–1150

Table 6. *(Continued)*

Sample number	Formation[1]	Latitude and longitude	Color[2]	Plasticity[3]	Water of plasticity, percent	Drying defects[4]	Drying shrinkage, percent	Dry strength[5]	pH	Effervescence with HCl[6]	Bloating test[7]	Vitrification temperature, degrees C
19	Sr	41°05′49″N 76°53′20″W	g	s	16.2	n	2.5	f	8.0	s	n	1100–1150
20	Sr	41°05′46″N 76°53′17″W	g	s	17.2	n	2.5	f	7.8	s	n	1100–1150
21	Sr	41°05′43″N 76°53′15″W	g	s	17.2	n	5.0	f	7.7	s	n	1150–1200
22	Sr	41°05′40″N 76°53′12″W	g	s	16.8	n	2.5	f	7.9	s	n	1100–1150
23	Sr	41°05′38″N 76°53′09″W	g	s	16.8	n	2.5	p	7.9	n	n	1150–1200
24	Sr	41°05′35″N 76°53′06″W	t	s	18.0	n	2.5	f	7.8	n	n	1150–1200
25	Do	41°08′29″N 76°59′52″W	r	p	24.8	- - -	2.5	g	4.9	n	n	1050–1100
26	Do	41°08′29″N 76°59′52″W	r	s	14.6	- - -	2.5	g	5.5	n	n	1200–1250

*Based on preliminary tests by the Tuscaloosa Metallurgy Research Laboratory of the U. S. Bureau of Mines.

[1] Formation or unit: Qsr — Shale-chip rubble; Dtr — Trimmers Rock; Dh — Harrell; Dm — Mahantango; Dmr — Marcellus; Sw — Wills Creek; Sb — Bloomsburg; Sr — Rose Hill; Do — Old Port.

[2] Colors: b — brown; rb — red brown; t — tan; g — gray; lt g — light gray; dk g — dark gray; bk — black; r — red.

[3] Plasticity: s — short; p — plastic.

[4] Drying defects: n — none.

[5] Dry strength: p — poor; f — fair; g — good.

[6] Effervescence: n — none; s — slight.

[7] Bloating: n — negative; p — positive.

[8] Samples 17–24 are consecutive collections of the upper 90 percent of the Rose Hill Formation exposed along U. S. Route 15 south of Allenwood, 3 to 3.5 km (1.9 to 2.2 m) south of the mapped area.

made by the stiff-mud process. However, the short workability is desirable in the soft-mud and the dry-press processes, and these processes are used for making building and facing brick. The Rose Hill Formation is suitable for such brick, except that it is locally slightly calcareous. All eight samples melted before reaching 1200°C (2200°F), so that the maturing temperatures are less than 1125°C (2050°F). The Bloomsburg is also suitable, except for being slightly calcareous in some layers. It melts at 1150°C (2100°F). Currently, both the Rose Hill and Bloomsburg Formations are being utilized for brick manufacturing in Watsontown, 4 km (2.5 mi) south of the mapped area. The Wills Creek is unsuitable because of significant carbonate content. The Marcellus Formation is only marginally suitable for bricks, because of a rather low melting temperature (1100 to 1150°C, or 2000 to 2100°F) and a slight carbonate content in some layers. The noncalcareous portions of the Mahantango are only marginally useful for brick because of their very short firing range (1000°C, or 1800°F). Both the Harrell and the Trimmers Rock Formations are not suitable because of low melting temperatures and the few interbeds of slightly calcareous shales. Both samples of shale-chip colluvium are suitable for building and facing brick, possessing a fairly wide firing range (1050 to 1175°*C*, or 1900 to 2150°F). However, the rather small size of these deposits and the uncertainties of their location limit them from any large-scale exploitation for brick manufacturing.

Refractory Clays

None of the sampled shales are suitable for refractory clay use because of the low melting temperatures.

Stoneware and Pottery

None of the sampled shales are suitable for stoneware or pottery, primarily because of their short workabilities.

Old Port Shale

An exceptional red shale occurs at the top of the Old Port Formation, above the Ridgeley Sandstone, in White Deer Valley along the western edge of the Montoursville South quadrangle (41°08′29″N/76°59′52″W). It is slightly silty, moderate reddish brown (approximately 10R4/5), has a poor to fair fissility and a moderately slippery feel, and occupies about a 3-m (10-ft) interval between the white, medium-grained Ridgeley Sandstone and the dark-gray shales of the lower part of the Onondaga Formation. Where it is weathered in situ, it occurs as a red, sticky clay. It has not been observed elsewhere in the mapped area and it is not present at Montoursville. How far it extends throughout White Deer Valley from this locality is not known because of the extensive cover of glacial till over much of the valley.

It is exceptional because of its high iron and low manganese and sodium content (Table 7). It is not a likely source for iron ore because of its limited thickness and areal extent. The clay would perhaps be suitable as a color pigment in low-quality paints, but the iron content of the shale is too low for such use. However, the shale may be usable for coloring cement block, depending on how strongly it can impart its color (personal communication from N. C. Trivedi, 1977, to R. C. Smith, II, to author).

The ceramic properties differ considerably between the shale and the clay (see Table 6, samples 25 and 26 respectively; see also Appendix 1). The shale is short and vitrifies at a rather low temperature (1100°C, or 2000°F) with high shrinkage. In contrast, the clay is plastic and fires well up to 1200°C (2200°F), making it suitable for structural clay products (such as building and floor brick).

Table 7. Atomic Absorption Analyses of Red Shale and Red Clay at the Top of the Old Port Formation in White Deer Valley

Oxides	Red shale	Red clay
SiO_2	49.40	68.30
Al_2O_3	13.75	18.85
Fe_2O_3	25.90	5.10
CaO	0.20	0.22
MgO	0.53	0.61
MnO	0.011	0.004
Na_2O	0.08	0.09
K_2O	2.40	2.85
TiO_2	0.71	1.00

The clay was collected in a channel sample from the south wall of the borrow pit opened for the friable sand of the uppermost Old Port Formation, over a stratigraphic interval of approximately 1.5 m (4.9 ft). The shale was collected as a grab sample from among shale chips scattered about the field just west of the borrow pit. Borrow pit is located at 41°08′29″N/76°59′52″W.

TRIPOLI

Tripoli (rottenstone) is a shale having finely particulate silica, used as a paint filler and as a bonding agent in brake linings. Tripoli has been produced from a quarry in the Marcellus Formation by the Keystone Paint and Filler Company.

The quarry, 2.3 km (1.4 mi) southwest of Muncy (41°11′23″N/76°40′17″W) along the east bank of the Susquehanna River, was opened in about 1885, but operations in it have since ceased. The basal Marcellus was utilized, and the limestone beds and calcareous nodules were cast aside. Although the Marcellus is relatively thick (105 to 150 m, or 345 to 492 ft) and extends across the mapped area in three belts, the potential for tripoli is not large because of the extensive, thick surficial deposits overlying much of the formation, and because of the availability of other types of materials for paint filler.

METALLIC MINERALS

Mineral occurrences throughout the mapped area were not numerous, nor particularly noteworthy, except in two quarries, the Lime Bluff quarry northeast of Muncy, and the Lymehurst quarry between Williamsport and Montoursville. Both of these exhibit minor lead and zinc mineralization.

In the Lymehurst quarry, owned by George Logue, galena and sphalerite occur in minor amounts in a calcite vein near the top of the Tonoloway Formation (R. C. Smith, II, written communication, 1974). These two minerals also occur in nearby slickensided stylolites. Trace amounts of purple fluorite, anglesite, pyrite, and barite(?) are present as well. Analysis of a limonite-pyrite gossen from this quarry yields: Co, 20 ppm; Ni, 15 ppm; Cu, 205 ppm; Zn, 1.7 percent; As, 720 ppm; Pb, 370 ppm; and Ag, 3 ppm. The last four values are high, particularly the zinc.

Cubic galena crystals, bright orange sphalerite, and anglesite are present in minor amounts in a calcite vein in the Lime Bluff quarry (R. C. Smith, II, written communication, 1973). This mineralization occurs in an area of disrupted bedding that lies on a projection of a nearby fault. Trace minerals are malachite, smithsonite, enargite(?), pyrite, and purple fluorite.

A ferroan-dolomite and either barite or celestite occur in the Keefer Formation south of Allenwood. Pyrite appears in the Old Port, and is common, replacing fossils, in the Onondaga Formation. Limonite and pyrite occur in the darker shales of the Mahantango Formation, and siderite nodules are present in the Marcellus and are common in the upper part of the Mahantango Formation. A red ferroan-argillite lies between the Ridgeley Sandstone and the gray shales of the Onondaga Formation in White Deer Valley.

OIL AND GAS

No wells for oil or gas have been drilled within the mapped area. A number of wells, however, have been drilled within 50 km (30 mi) of these quadrangles, both to the northwest, north, and northeast in the Allegheny Plateau province, and to the west, south, and east in the Valley and Ridge province (Figure 26; Table 8). Much of the drilling activity occurred in the early and middle 1950's with poor results, and it came to an end in 1963. No more wells were drilled in this area until No. 1 Mary Louise Hess (number 4, Figure 26 and Table 8) was completed in late 1976. This is the discovery well of the Salladasburg field, the first producing field in the Williamsport area, and is the easternmost gas production from the Oriskany in Pennsylvania.

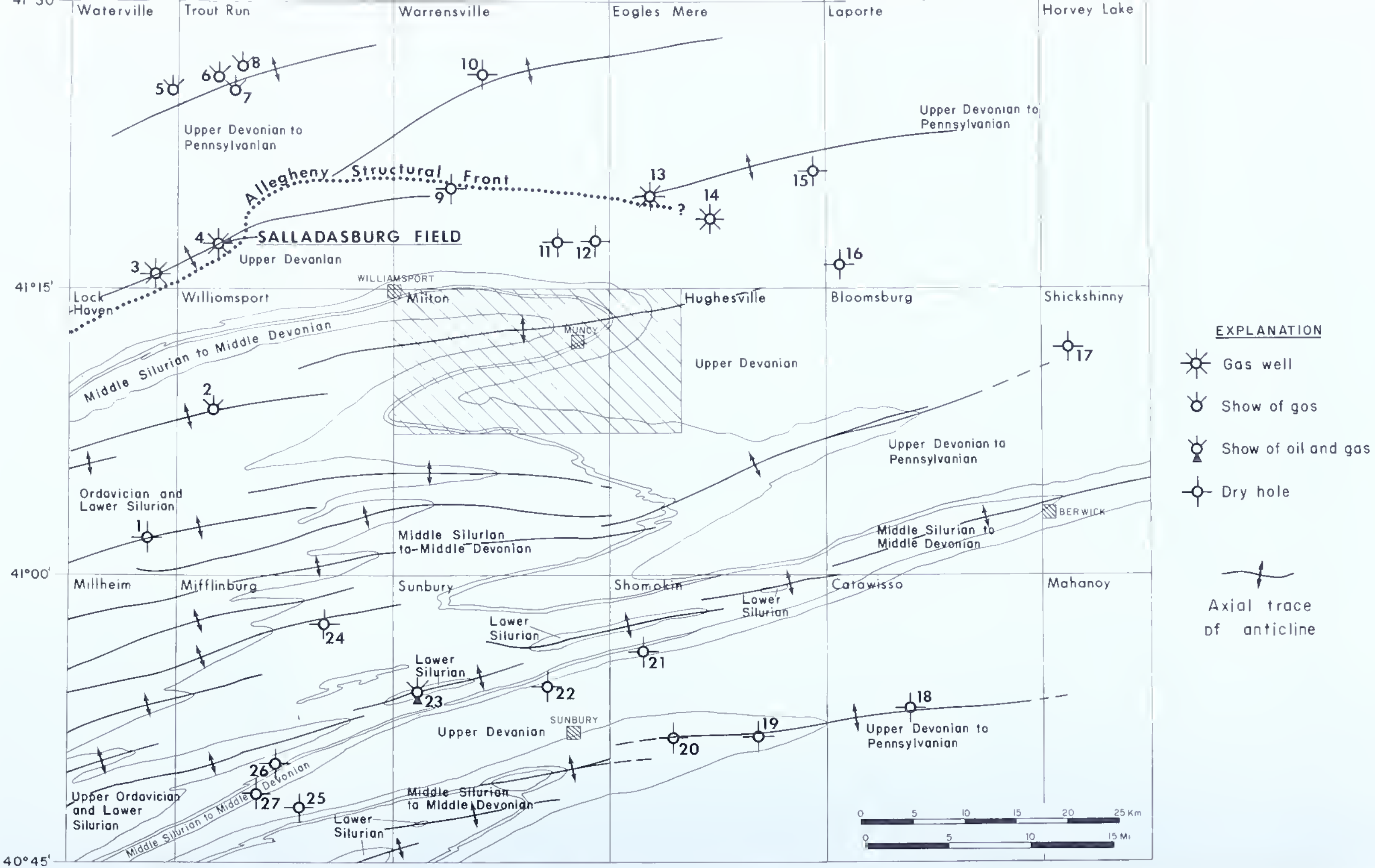

Figure 26. Map of the Williamsport area showing locations of nearby oil and gas wells. See Table 6 for identifying list. All of the wells were dry or yielded only a show of gas or oil, except for three in the Salladasburg field

Table 8. *Oil and Gas Wells in the Williamsport Area*

No.[1]	Well	7-1/2-minute quadrangle	Formations penetrated		Total depth, feet	Reference[2]
			Highest	Deepest		
1	Clifford Walizer #1	Loganton	Bellefonte	Gatesburg	4532	M 39, p. 60
2	W. E. Snyder #1	Linden	Bellefonte	Gatesburg	5808	M 39, p. 98
3	Robert Sulik #1	Waterville	Catskill	Helderberg	7264	PR 192
4	Mary Louise Hess #1	Salladasburg	Catskill	Helderberg	6325	PR 190, p. 49
4a	Robert M. Brucklacher #1	Salladasburg	Catskill	Helderberg	6305	PR 191, p. 38
4b	Charles N. Emig #1	Salladasburg	Catskill	Helderberg	6462	PR 191, p. 38
4c	Fred Myers #1	Salladasburg	Catskill	Helderberg	6920	PR 192
5	Wm. P. Day #1	English Center	Burgoon	Helderberg	7990	PR 160, p. 51
6	E. E. Hughes #1	White Pine	Catskill	Shriver	7579	M 39, p. 98; M 45, p. 114
7	J. F. Stryker #1	White Pine	Catskill	Helderberg	7227	PR 165, p. 39
8	Wallace Codney #1	White Pine	Catskill	Helderberg	7814	M 39, p. 98
9	Yeagle #1	Montoursville North	Catskill	Lock Haven	2274	7-15-77
10	Ambrose E. Ging #1	Bodines	Catskill	Helderberg	8118	M 39, p. 98
11	Peri Woodley #1	Huntersville	Catskill	Bradford	1710	2–4–77
11a	Peri Woodley #2	Huntersville	Catskill	Lock Haven	1706	3–4–77
12	Grover Burkhardt #1, 3	Huntersville	Catskill	Mahantango	6854	M 39, p. 98
13	Arnold M. Fox & Sons #1	Picture Rocks	Catskill	Lock Haven	4048	9–12–75
14	Chester G. Shaner #1	Picture Rocks	Catskill	Helderberg	7836	PR 191, p. 38
14a	Donald L. Fulmer #1	Picture Rocks	Catskill	Lock Haven	2313	7–2–77
15	Arthur W. Bennett #1	Sonestown	Catskill	Juniata	12,343	M 39, p. 110
16	Frank Tranor #1	Elk Grove	Catskill	Mahantango	7169	M 45, p. 114
17	Nellie J. Harrison #1	Shickshinny	Trimmers Rock	Helderberg	5555	M 39, p. 97
18	Knarr #1	Catawissa	Catskill	Tonoloway	7445	M 45, p. 84
19	Geo. C. Krick #1	Shamokin	Mahantango	Keyser	1384	M 39, p. 100; M 45, p. 116

Table 8. *(Continued)*

No.[1]	Well	7-1/2-minute quadrangle	Formations penetrated Highest	Formations penetrated Deepest	Total depth, feet	Reference[2]
20	Fox #1	Trevorton	Mahantango	Keyser	1820	M 39, p. 100
21	Epler #1	Riverside	Mahantango	Bloomsburg	4888	PR 166, p. 44
22	Hillbish #1	Northumberland	Trimmers Rock	Bloomsburg	5804	PR 165, p. 39
23	Solomon #1	Lewisburg	Tuscarora	Bellefonte	8002	M 39, p. 110; M 45, p. 128
24	Iddings #1	Mifflin	Upper Silurian	- - -	2470	M 39, p. 110
25	Moyer #1	Middleburg	Trimmers Rock	Tonoloway	5780	M 45, p. 123
26	Carl Herbster #1	Beavertown	Tonoloway	Bloomsburg	2960	M 45, p. 123
27	Albert #1	Beavertown	Mahantango	Rose Hill	5965	M 45, p. 123

[1] Numbers refer to wells located on geologic map, Figure 23. Letters following numbers (e.g., 4a, b, c) represent additional wells drilled within 3 km (2 mi) of an initial well.

[2] M 39—Fettke (1956)
M 45—Lytle and others (1961)
PR 160—Lytle and others (1962)
PR 165—Lytle and others (1963)
PR 166—Lytle and others (1964)
PR 190—Lytle and others (1977)
PR 191—Heyman and Cozart (1978)
PR 192—Piotrowski and others (1979)

The earliest (1951 to 1955) drilling consisted of deep tests of horizons that are productive in western Pennsylvania—the Lower Devonian Ridgeley (Oriskany), the Lower Silurian Tuscarora, and the Upper Cambrian Gatesburg. They were all located on the crests of the largest anticlines in the Valley and Ridge province (numbers 1, 2, and 23, Figure 26) and the Allegheny Plateau province (numbers 6, 8, 10, and 15). All of these wells were abandoned, with at most a show of gas and/or salt water in the Oriskany, the Gatesburg, or the Middle to Upper Ordovician. Despite the negative results, these wells provided stratigraphic information in parts of the Paleozoic section (particularly the Cambrian and Lower Ordovician) that are not exposed at the surface in this area, and they produced structural data on the shapes of the anticlines.

Apparently this initial, unsuccessful activity stimulated considerable local interest in searching for gas and oil, because in the next few years (1953 to 1957) a number of wells, for the most part locally financed, were drilled; seven of them are south of the mapped area, west and east of Sunbury, and three others are to the east and north of Muncy. Four of the wells (numbers 17, 18, 19, and 20) were located on the crests of major anticlines and reached the Ridgeley (Oriskany); all four were dry and abandoned. The four wells west of Sunbury (numbers 24, 25, 26, and 27) and the two north and northeast of Muncy (numbers 12 and 16) were apparently drilled with total disregard of the geology. The last two (numbers 12 and 16) spudded in the Catskill and were terminated in the Mahantango, several hundred feet above the Ridgeley; no structure exists at the surface around either well, only a uniform northward dip. Of the four wells west of Sunbury, two (numbers 25 and 27) are located near a major synclinal hinge, where no Ridgeley is present; the other two (numbers 24 and 26) spudded in the Upper Silurian and never reached the Tuscarora.

A few years later (1962 and 1963), two more wells (numbers 21 and 22) were drilled north of Sunbury, some distance south of an anticlinal crest. Both passed through the Ridgeley and had only a show of gas, and both were completed in the Bloomsburg. At about the same time (1961 and 1962), two wells (numbers 5 and 7) were drilled in the Plateau near a previous test on the crest of the Cogan House anticline. Both penetrated the Ridgeley, but there was only a show of gas, even after fracturing (8 Mcfgpd[1] in number 5), and both were abandoned.

Drilling activity in this part of the state thereupon ceased until the Salladasburg field was discovered in late 1976 on the Tombs Run anticline by the No. 1 Mary Louise Hess well (number 4 in Figure 26). During the drilling of this well, the Mahantango yielded 1,500 Mcfgpd initially, but this soon declined to 300 Mcfgpd. The Ridgeley (Oriskany) initially yielded 250 Mcf gas, which was increased to 1,100 Mcfgpd after fracturing. Two development wells have since been drilled nearby, yielding 787 Mcfgpd (number 4a) and 15 Mcfgpd (number 4b). A fourth well (number 4c) was completed in late 1978 as an offset; it had only a slight show of gas from the Upper Devonian Lock Haven Formation and was abandoned. A fifth well (number 3) was drilled 7 km (4 mi) southwest of the Salladasburg field on the same anticlinal structure; it resulted in a new pool discovery (Tombs Run pool), producing 40 Mcfgpd gas (after fracturing) from the Ridgeley.

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[1] Thousand cubic feet of gas per day

Renewed drilling to the east, north, and northwest of Muncy has not led to a new field discovery. One company has cleaned out one well (number 12), apparently in preparation for deepening, and drilled three more (numbers 11, 11a, and 9) in nearby areas of uniform northward dip. Numbers 11 and 11a were tests of the Upper Devonian sands that are so productive in western Pennsylvania, but both were dry. Number 9 was intended to test the Ridgeley, but it was abandoned in the Lock Haven. Of three recent wells northeast of Muncy, one (number 14) was an unsuccessful test of the Ridgeley; the other two (numbers 14a and 13) were drilled to the Upper Devonian Lock Haven Formation and yielded between 10 and 35 Mcfgpd, but are considered noncommercial because of these low flows. There has been no further activity in the vicinity since late 1978.

The initial, serious exploratory attempts in the 1950's did not give much encouragement or hope for finding significant sources of gas or oil in the Williamsport area. However, the discovery of the Salladasburg field, and the more recent success of the No. 1 Texasgulf Inc. Tract (and the No. 1 C & K Coal?) test of the Tuscarora (reported at 37,000 Mcfgpd) some 60 km (40 mi) southwest of the Salladasburg field, indicate that the very limited early exploration of this area may easily have missed sizable reservoirs. An indication of renewed interest is the great increase in seismic exploration in this part of Pennsylvania in the past few years. As the demand for gas continues to increase, more wells will undoubtedly be drilled here.

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GLOSSARY

Algal. Pertaining to algae, diverse aquatic plants (e.g., seaweeds), many of which produce calcareous sedimentary structures.

Allegheny Plateaus province. The north-central and western parts of Pennsylvania, containing high plateaus and low-amplitude folds.

Allegheny Structural Front. Boundary between the low-amplitude folds of western Pennsylvania and the large-amplitude folds of central Pennsylvania.

Alluvium. Loose sand, gravel, silt, and mud deposited by running water in valleys.

Altonian. A phase of continental glaciation, during the time span from 100,000 to 28,000 years before the present.

Amplitude. The height of a fold.

Anglesite. A lead sulfate mineral, valued as an ore of lead.

Angular. Said of sedimentary particles having sharp edges and corners. See also *Rounded.*

Anticline. A fold of layered rock in which the layers dip away from the hinge; it is convex upward. Compare *Syncline.*

Apex. The highest point on an alluvial fan, where the stream forming the fan emerges from the valley above.

Argillaceous. Pertaining to a sedimentary rock containing an appreciable amount of clay.

Axial trace. The trace of a fold hinge (axial surface) on the earth's surface.

Barite. A barium sulfate mineral, the principal ore of barium.

Bed. A sedimentary layer of relatively homogeneous material separated from adjacent layers by visually more or less well defined boundary surfaces.

Bedrock. A general term for solid rock that underlies soil or other surficial material.

Bimodal. Said of a surficial deposit composed of a large percentage of particles of two different sizes, and few particles of the intervening sizes.

Bioclastic. Consisting of broken remains of organisms, such as shell fragments.

Bioturbated. Refers to sediments once churned and stirred by organisms.

Birdseye. An irregular patch of clear calcite in a limestone.

Borrow pit. A shallow excavation from which soil and weathered rock is removed, generally for use as fill.

Boulder. A rock mass having a diameter greater than 256 mm (10 in.); larger than a cobble.

Brachiopod. A marine animal that is similar to a clam, but whose two shells are unequal in size.

Bryozoan. A marine animal that has a calcareous skeleton and usually lives on a shallow sea floor in colonies.

Calcarenite. A limestone consisting predominantly of fragmental calcite particles of sand size.

Calcareous. Refers to rocks containing calcite, in particular rocks in which the grains are cemented with calcite.

Calcilutite. A limestone consisting predominantly of fragmental calcite particles of clay size.

Calcirudite. A limestone consisting predominantly of fragmental calcite particles of gravel size.

Calcisiltite. A limestone consisting predominantly of fragmental calcite particles of silt size.

Calcite. A calcium carbonate mineral, a common constituent of rocks.

Carbonate. Includes calcite, dolomite, and siderite, mineral compounds of calcium and CO_3, magnesium and CO_3, and iron and CO_3, respectively.

Cavity. An empty space within a rock from which rock material has been removed by solution.

Celestite. A strontium sulfate mineral, the principal ore of strontium.

Channel. A linear watercourse eroded out from underlying sediments of an alluvial floodplain, and filled with similar sediments.

Chert; cherty. A sedimentary rock consisting of extremely fine grained (cryptocrystalline) silica; pertaining to beds containing chert, usually as nodules.

Chroma. Pertaining to the vividness of a color.

Clast; clastic. An individual fragment of a rock, produced by mechanical weathering from a larger rock body; pertaining to beds containing clasts.

Clay. A rock or mineral fragment smaller than very fine silt (less than 0.0039 mm in size); deposit containing mostly clay-sized particles.

Cleavage. Closely spaced planar surfaces produced by deformation, along which the rock tends to split or break.

Coarse grained. See *Grain size.*

Cobble. A rock fragment between a pebble and boulder in size, between 6.4 and 25 cm (2.5 and 10 in.) in diameter.

Coelospiroid. Pertaining to a small, ribbed, oval-shaped brachiopod.

Colluvium. Loose, generally heterogeneous, structureless soil and/or rock material deposited chiefly by mass wasting.

Columnal. A single, usually circular plate that was a segment of a column (stem) supporting a marine animal, such as a crinoid.

Concentric fold. A fold in which, in cross section, the beds are in the form of circular arcs.

Concretion. A rounded, usually ellipsoidal or irregularly shaped, mineral mass precipitated from aqueous solution in the pores or cavities of a sedimentary rock.

Conformable. Said of beds or formations in which the layers were formed one above the other in uninterrupted deposition.

Conglomeratic. Pertaining to a clastic sedimentary rock containing significant amounts of gravel.

Contact. A surface between two different types or ages of rocks.

Crinoid. A marine animal having a globular body and radiating "arms," connected to the substrate by a column (stem).

Crossbedding. Pertaining to a layer containing minor beds inclined to the layer surface.

Crystal. A homogeneous solid body of a chemical element or compound characterized by a regular, repeating atomic arrangement.

Cylindrical. Pertaining to a fold which can be generated by moving a line (the fold axis) parallel to itself through space.

Deformation. The change of shape, texture, or attitude of a rock mass by earth forces (stresses) resulting in folds, faults, cleavage, and other geologic structures.

Dendritic. A drainage pattern in which the streams branch irregularly in all directions, much as oak or maple tree branches.

Deposit; deposition. Any material that has accumulated by some natural process; the accumulation of material into beds, veins, or irregular masses.

Devonian. The time period between 395 and 345 million years ago; pertaining to any deposit formed during this time period.

Dip. The vertical angle between a surface, such as bedding or a fault, and the horizontal, measured perpendicular to the strike of the surface.

Dip fracture. A fracture subparallel to the dip direction, or approximately perpendicular to the strike of bedding.

Dissolution. The removal of rock material by solution, leaving a space or cavity.

Distorted. Pertaining to objects whose shape has been changed by applied stresses.

Dolomite. A calcium-magnesium carbonate mineral; a common rock-forming mineral.

Dolosiltite. A dolomite rock consisting primarily of particles of silt size.

Domain. An area or volume within which structural attitudes are constant, and surrounded by domains of different structural attitudes.

Drainage. The network of surface streams and subsurface conduits through which excess water is removed from an area.

Enargite. A copper, arsenic sulfide mineral; an important ore of copper.

Erosional remnant. A deposit or rock mass remaining after erosion has removed surrounding material.

Extension fracture. A fracture that develops parallel to the greatest compressive stress and perpendicular to the least compressive stress.

Fault. A surface or zone of rock fracture along which there has been displacement.

Ferroan dolomite. A dolomite containing a significant amount of iron.

Ferroan argillite. A shale or mudstone containing a significant amount of iron.

Fine grained. See *Grain size.*

Fissile; fissility. Capable of being easily split along closely spaced planes; property of a rock (usually a shale) that causes it to split easily, parallel to bedding.

Flat bedded. Pertaining to a layered sequence in which the bedding surfaces are planar and smooth.

Flexural slip. Pertaining to a fold produced by slip between layers, and in which layer thickness is unchanged across the fold.

Floodplain. A relatively flat terrain in a valley adjacent to a stream or river channel, which is covered with water when the stream overflows its banks.

Flow deformation. Deformation without permanent loss of cohesion, and which is not elastic.

Fluorite. A calcium fluoride mineral, the principal ore of fluorine.

Fluvial. Pertaining to a river or stream.

Fold. A curve or bend of an initially planar feature such as a bedding plane, and usually a result of deformation.

Fold axis. A line about which the fold layers are curved or bent.

Fold wavelength. The distance between the hinges of adjacent anticlines (or synclines).

Formation. A body of rock, usually in tabular form and of considerable thickness, containing a distinctive lithology or combination of lithologies.

Fossil; fossiliferous. The remains, trace, or imprint of a plant or animal that has been preserved in the rock; pertaining to a rock containing fossils.

Fossil hash. A lens or bed composed predominantly of fossils and/or fossil fragments.

Fracture. A break in a rock induced by stress.

Friable. Said of a rock that crumbles easily.

Galena. A lead sulfide mineral; the most important ore of lead.

Glacial till. A deposit produced by a glacier or ice sheet.

Glacier. A large mass of ice formed on land by the compaction of snow, which moves downslope or across the land by creep and flow.

Grain. A mineral or rock particle generally less than a few millimeters in diameter.

Grain size. Pertaining to the mean size of the constituent particles of a rock. The terms and their size limits are:

Grain size	Upper size limits	Corresponding Φ values
Boulder	>256 mm	
Cobble	256 mm	−8
Pebble	64 mm	−6
Granule	4 mm	−2
Very coarse sand	2 mm	−1
Coarse sand	1 mm	0
Medium sand	0.5 mm	1
Fine sand	0.25 mm	2
Very fine sand	0.125 mm	3
Silt	0.0625 mm	4
Clay	0.0039 mm	8

Gravel. An unconsolidated deposit, consisting predominantly of pebbles (particles larger than sand; greater than 2 mm in diameter).

Gravel bar. An elongate gravel deposit on a stream or river bed.

Graywacke. A sandstone composed of more than 25 percent rock fragments.

Gypidula coeymanensis. A smooth, oval-shaped brachiopod, commonly occurring in the Old Port Formation.

Hackly. Said of a rock fracture that yields a jagged surface.

Headwater. The upper part of the drainage basin including the stream source.

Hematite. A common iron oxide mineral, the principal ore of iron.

Hinge. The part of a fold having maximum curvature or bending.

Homoclinal. A rock mass in which the beds have the same dip throughout.

Hummocky. Pertaining to a topographic surface composed of low, rounded, equidimensional mounds or knolls.

Illinoian. One of four Pleistocene continental glaciations, during the time span from 375,000 to 150,000 years before the present.

Interbed. A bed of one lithology between beds of a differrent lithology.

Internal structure. A sedimentary structure, such as a lamina, crossbed, or ripple mark, that is present within a bed.

Joint. A planar fracture having little or no visible displacement.

Kink band. A tabular, more or less parallel-sided rock volume (zone), within which bedding has been rotated relative to bedding outside the zone.

Kink-band fold. A fold produced by the convergence of two kink bands.

Kink plane. The boundary of a kink band, where bedding is most sharply curved or bent.

Lamina; *laminated.* The thinnest unit layer in sedimentary rocks, less than 1 cm thick; a bed or rock sequence containing laminae.

Layer. A tabular body of rock; a bed.

Leach. To selectively remove soluble constituents from a rock mass by percolating water.

Left-lateral. See *Strike-slip fault.*

Leiorhynchus limitare (Vanuxem). A small, globular brachiopod having well-developed ribs.

Leptocoellina acutiplicata. A flat brachiopod having well-developed ribs, of Middle Devonian age.

Limb. One side of a fold, within which bedding usually dips in the same direction.

Limestone. A sedimentary rock consisting predominantly of calcium carbonate.

Limonite. An iron oxide mineral of variable composition; a common weathered product of other iron minerals.

Lingula. A small, elongate, thin- and smooth-shelled brachiopod, present in rocks of Ordovician age to present.

Lithic. Pertaining to rock properties.

Lithology. The description of rocks.

Lower Devonian. The earliest portion of the Devonian span of time.

Lower Silurian. The earliest portion of the Silurian span of time.

Malachite. A bright-green copper carbonate mineral; an ore of copper.

Marine. Pertaining to a sea or ocean environment, and applied to rocks deposited in such environments.

Matrix. The smaller sized material filling the spaces between the larger grains in a sedimentary rock.

Medium-bedded. Applied to sedimentary beds between 10 and 30 cm (4 and 12 in.) thick.

Medium grained. See *Grain size.*

Member. A portion, or subdivision, of a formation, in which the rocks are distinct in some way from the rocks of the rest of the formation.

Microlithon. A small, undeformed portion of rock surrounded by deformed material (in particular, cleavage zones).

Middle Devonian. The medial portion of the Devonian span of time.

Mud. An unconsolidated material consisting predominantly of clay-sized particles (less than 0.0039 mm in size).

Mudstone. A rock composed predominantly of mud and having the composition and texture, but not the fissility, of a shale.

Nodular limestone. A limestone composed of calcareous nodules in a matrix of similar or contrasting calcareous material.

Nodule. A small, irregular or semirounded body of rock material surrounded by a matrix of similar or markedly different lithology.

Noncalcareous. Not containing calcareous material.

Noncylindrical. Pertaining to a fold that is not cylindrical.

Oncolite; *oncolitic.* A small, often spheroidal, concentrically laminated, calcareous sedimentary structure of algal origin; pertaining to a rock containing oncolites.

Orbiculoidea. A small circular black-shelled brachiopod, characteristic of the Onondaga Formation.

Ordovician. The time period between 500 and 435 million years ago; pertaining to any deposit formed during this time period.

Orthorhynchula zone. A fairly thin sequence of beds at the top of the Reedsville Formation, which contain medium-sized, broadly elliptical, strongly ribbed brachiopods, *Orthorhynchula.*

Ostracodes. Small animals that have two shells; related to shrimp.

Outcrop. Rock exposed at the Earth's surface.

Outwash. Sand and/or gravel removed from a glacier by water and deposited near its margins.

Overturned. Said of a fold limb, or fold, in which the rock layers have been rotated beyond the perpendicular, and in which the bed sequence appears reversed.

Parallel-bedded. Said of a sedimentary sequence in which the bedding planes are parallel.

Parting. A surface in a rock mass along which the rock separates easily; e.g., a bedding surface or a fracture surface.

Pebble. A small, often rounded rock fragment between a sand grain and a cobble in size, and between 4 and 64 mm (0.16 and 2.5 in.) in diameter.

Pelecypod. A marine animal that has two equal shells; a clam.

Pelletal. Pertaining to a carbonate rock containing small, usually ellipsoidal clasts of homogeneous calcareous material.

Plunge. The vertical angle between the horizontal and a linear structure, such as fold axis, or slickenlines.

Principal plane (of stress). One of three mutually perpendicular planes, upon each of which the shear stress is zero.

Pyrite. A brass-yellow iron sulfide mineral; "fool's gold."

Quadrangle. A four-sided area bounded by latitudinal parallels and longitudinal meridians, commonly represented by topographic and geologic maps.

Quartz. A colorless (usually) silicon oxide; a very common rock-forming mineral.

Quartzite. A very hard sandstone consisting almost entirely of quartz grains cemented with silica.

Quartzose. Pertaining to a rock containing quartz as the principal constituent.

Quaternary. The time period from 2 million years ago to the present; pertaining to any deposit formed during this time period.

Recessional moraine. A linear low ridge of till material built at the end of a glacier during a temporary pause in its final retreat.

Red beds. A sedimentary sequence predominantly red in color because of the presence of significant hematite.

Regolith. The loose weathered rock and soil lying above, and derived from, the underlying bedrock.

Relief. The actual physical shape of the Earth's surface, particularly with respect to height.

Right-lateral. See *Strike-slip fault.*

Ripple mark. An undulatory sedimentary surface consisting of small, subparallel ridges and troughs; commonly found in sandstones and siltstones.

Rock. Any naturally formed material composed of two or more (occasionally ore) minerals.

Rounded. Pertaining to the shape of a clastic particle, particularly the absence of sharp corners and edges.

Sand. An unconsolidated material consisting predominantly of sand-sized particles (between 0.0625 and 2 mm in diameter).

Sandstone. A clastic sedimentary rock composed predominantly of sand-sized particles.

Sedimentary rock. A rock resulting from the cementation or consolidation of loose sediment, or chemical precipitation from a solution (as sea water).

Shale. A fine-grained sedimentary rock consisting predominantly of particles of clay size and possessing a bed-parallel fissility.

Shear fracture. A fracture that develops at an angle to the greatest compressive stress, and along which movement occurs.

Siderite. A brownish iron carbonate mineral, commonly found in nodules in shale; an ore of iron.

Silica; siliceous. Silicon dioxide; said of a rock containing abundant silica.

Silt. An unconsolidated material consisting predominantly of silt-sized particles (between 0.0039 and 0.0625 mm in diameter).

Siltstone. A clastic sedimentary rock composed predominantly of silt-sized particles.

Silurian. The time period between 435 and 395 million years ago; pertaining to any deposit formed during this time period.

Sinkhole. A shallow to deep depression formed by dissolution of limestone and the collapse of overlying material into the cavity.

Slickenlines. Parallel striations on a slickensided surface along which movement of rock has occurred.

Slickenside. A polished surface along which movement of rock has occurred, commonly producing slickenlines which indicate direction of movement.

Smithsonite. A white zinc carbonate mineral; an ore of zinc.

Sole marking. A convex irregularity on the bottom of sandstone or siltstone beds, formed by infilling of a depression in the underlying bed.

Solifluction. Slow downslope flow of water-saturated surficial material.

Solution rounded. Pertaining to the rounding of sharp corners and edges of rocks by dissolution.

Sorted (well). Said of a sediment or rock containing particles of uniform size.

Sowerbyella-Onniella community. An assemblage of brachiopods characteristically found at the top of the Reedsville Formation.

Sparry calcite (birdseye). Clear, coarse-grained calcite crystal.

Sphalerite. A brown or black zinc and iron sulfide mineral; an ore of zinc.

Stereogram. A graphic, circular diagram on which three-dimensional orientation data can be represented in two dimensions.

Strain ellipsoid. A three-dimensional solid representing the principal strains recorded in a rock.

Stratification. The deposition of material into layers.

Stratified drift. Sorted and layered material from a glacier, deposited by a meltwater stream.

Stress. The force (per unit area) acting at a given point in a solid.

Stress field. The state of stress from point to point in a given solid.

Strike. The trend of a horizontal line on a surface, such as bedding or a fault.

Strike fracture. A fracture whose strike is subparallel to that of the bedding.

Strike-slip fault. A fault, usually subvertical, on which movement has occurred parallel to the strike of the fault; right-lateral, the rocks on the far side of the fault move to the right; left-lateral, they move to the left.

Structural front. A boundary between two areas or regions of different styles of structure.

Structural relief. The difference in elevation between the highest and lowest points on a given bed in a fold.

Structural terrace. A local area of subhorizontal beds within an area of inclined beds.

Structural trend. The predominant direction of fold axes, bedding strikes, fault strikes, cleavage, etc., in a local area or region.

Stylolite. An irregular surface, usually in limestones, along which soluble material has been dissolved, with consequent concentration of clay material.

Subangular. Said of particles that are free from sharp points and edges, but not smoothly rounded.

Subgraywacke. A sandstone composed of between 10 and 25 percent rock fragments.

Subrounded. Said of a particle that exhibits some of its original shape, but has corners and edges rounded into smooth curves.

Surface drainage. The network of streams at the Earth's surface that removes excess water from an area.

Surficial. Pertaining to unconsolidated material above bedrock.

Syncline. A fold of layered rock in which the layers dip toward the hinge; it is concave upward. Compare *Anticline.*

Systematic shale joint. A planar fracture in a shale, one of many of similar orientation.

Taconic clastic wedge. The body of clastic rocks deposited as a result of the Taconic orogeny in the time span from Late Ordovician through Early Silurian.

Tectonic. Pertaining to the deformation of regions in the Earth's crust, and the structures formed therein.

Tectonic grain. A pronounced parallelism of structural trends within a given area.

Terrace; alluvial. A level, flat-topped area in a valley, underlain by alluvial material and standing above the floodplain.

Terrigenous. Said of sediments and rocks derived from material on the land.

Thick bedded. Applied to sedimentary beds between 30 and 100 cm (12 and 39 in.) thick.

Thin bedded. Applied to sedimentary beds between 3 and 10 cm (1 and 4 in.) thick.

Till. Unsorted and unstratified material deposited by and underneath a glacier.

Transverse fault. A fault that has a trend (strike) at a large angle to the local structural trend.

Trellis drainage. A drainage pattern characterized by parallel main streams and intersected at nearly right angles by their tributaries.

Tributary stream. A stream flowing into a larger stream.

Trilobite. A marine animal that had an external skeleton and crawled about on the sea floor; trilobites lived between 600 and 225 million years ago.

Tripoli. A fine, porous, lightweight siliceous material derived from weathered rocks; used for polishing and as a paint filler.

Undulatory. Said of bedding that exhibits irregular rippling or wavy form.

Upper Devonian. The youngest part of the Devonian, from 360 to 345 million years ago; pertaining to deposits formed during this time period.

Upper Silurian. The youngest part of the Silurian, from 410 and 395 million years ago; pertaining to deposits formed during this time period.

Valley and Ridge province. A physiographic province characterized by long, linear valleys or ridges.

Vein. The mineral filling of a tabular (more or less) opening in a host rock.

Very thick bedded. Applied to sedimentary beds more than 100 cm (39 in.) thick.

Very thin bedded. Applied to sedimentary beds between 1 and 3 cm (½ and 1 in.) thick.

Weathered. Said of a rock that has been altered from its original state by chemical and mechanical processes at or near the Earth's surface.

Wedge fault. A fault at a relatively small angle to bedding, movement on which has resulted in a shortening of the beds.

Well rounded. Said of a particle that has a smoothly curved exterior and whose original shape is indiscernible.

APPENDIX 1

SLOW-FIRING TESTS FOR CERAMIC PROPERTIES OF SELECTED SHALES AND CLAYS[1]

Sample 1: Shale-chip rubble

Temp. °C	Munsell color[2]	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	3	2.5	13.1	26.0	1.98
1050	2.5YR5/8 Brownish orange	7	7.5	7.5	16.5	2.20
1100	2.5YR4/6 Strong brown	7	10.0	4.7	10.8	2.30
1150	2.5YR4/4 Moderate reddish brown	7	10.0	2.3	5.4	2.33
1200	2.5YR3/4 Moderate reddish brown	7	10.0	1.8	4.3	2.37
1250	- - -	- - -	Melted	- - -	- - -	- - -

Sample 2: Shale-chip rubble

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	3	2.5	17.8	32.4	1.82
1050	2.5YR5/8 Brownish orange	5	5.0	13.7	26.6	1.95
1100	2.5YR4/6 Strong brown	6	7.5	11.3	22.9	2.02

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[1] Based on preliminary data obtained from the Tuscaloosa Metallurgy Research Laboratory of the U. S. Bureau of Mines.

[2] Munsell color names were taken from American Society of Testing and Materials (1975).

Sample 2: Shale-chip rubble (continued)

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1150	2.5YR4/4 Moderate reddish brown	7	7.5	7.8	16.5	2.12
1200	2.5YR3/4 Moderate reddish brown	7	10.0	4.5	10.0	2.23
1250	- - -	- - -	Melted	- - -	- - -	- - -

Sample 3: Trimmers Rock Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	3	2.5	13.3	25.9	1.95
1050	2.5YR4/6 Strong brown	6	7.5	6.9	15.0	2.19
1100	2.5YR3/4 Moderate reddish brown	7	7.5	3.5	7.9	2.23
1150	- - -	- - -	Melted	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 4: Trimmers Rock Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	4	2.5	12.4	24.8	2.00
1050	2.5YR4/6 Strong brown	7	7.5	6.5	14.1	2.18
1100	- - -	- - -	Melted	- - -	- - -	- - -
1150	- - -	- - -	- - -	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 5: Harrell Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	4	5.0	12.6	25.1	2.00

Sample 5: Harrell Formation (continued)

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1050	2.5YR4/6 Strong brown	7	7.5	5.7	12.6	2.19
1100	- - -	- - -	Melted	- - -	- - -	- - -
1150	- - -	- - -	- - -	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 6: Mahantango Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	3	2.5	13.0	25.4	1.95
1050	2.5YR5/6 Grayish reddish orange	7	5.0	9.5	19.2	1.95
1100	2.5YR4/4 Moderate reddish brown	7	5.0	5.8	11.3	2.01
1150	- - -	- - -	Expanded	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

See Appendix 2 for results of bloating test.

Sample 7: Mahantango Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	3	2.5	12.7	24.8	1.95
1050	2.5YR5/6 Grayish reddish orange	6	5.0	8.9	18.6	2.06
1100	2.5YR4/4 Moderate reddish brown	7	5.0	4.9	10.2	2.08
1150	- - -	- - -	Expanded	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

See Appendix 2 for results of bloating tests.

Sample 8: Mahantango Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	3	2.5	13.5	25.9	1.92
1050	2.5YR5/6 Grayish reddish orange	6	5.0	9.5	19.2	2.03
1100	2.5YR3/4 Moderate reddish brown	7	5.0	3.7	7.7	2.08
1150	- - -	- - -	Expanded	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

See Appendix 2 for results of bloating tests.

Sample 9: Mahantango Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	5	2.5	11.1	22.2	2.00
1050	2.5YR5/6 Grayish reddish orange	6	5.0	5.8	12.2	2.12
1100	- - -	- - -	Expanded	- - -	- - -	- - -
1150	- - -	- - -	- - -	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 10: Marcellus Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	4	5.0	14.6	27.4	1.87
1050	2.5YR5/6 Grayish reddish orange	6	7.5	9.8	19.7	1.97
1100	2.5YR4/4 Moderate reddish brown	7	7.5	7.9	14.8	2.00
1150	- - -	- - -	Melted	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 11: Marcellus Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	5YR7/6 Moderate yellowish pink to moderate orange	7	5.0	16.8	30.3	1.80
1050	2.5YR5/6 Grayish reddish orange	8	7.5	9.3	18.7	1.95
1100	2.5YR4/4 Moderate reddish brown	8	7.5	6.4	12.5	2.00
1150	- - -	- - -	Melted	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 12: Marcellus Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	5YR7/6 Moderate yellowish pink to moderate orange	3	5.0	21.2	35.2	1.66
1050	5YR6/6 Light brown to moderate orange	6	10.0	11.4	21.8	1.92
1100	5YR4/4 Moderate reddish brown	7	10.0	7.3	14.6	2.01
1150	- - -	- - -	Melted	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 13: Wills Creek Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	7.5YR7/6 Light yellowish brown to moderate orange yellow	3	2.5	19.0	33.2	1.75

Sample 13: Wills Creek Formation (continued)

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1050	7.5YR7/4 Light yellowish brown	3	2.5	17.9	31.5	1.76
1100	7.5YR6/4 Light brown	7	5.0	14.2	26.1	1.83
1150	- - -	- - -	Melted	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 14: Bloomsburg Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR5/8 Brownish orange	6	5.0	7.4	16.0	2.17
1050	2.5YR4/6 Strong brown	7	10.0	3.3	7.9	2.37
1100	2.5YR3/4 Moderate reddish brown	8	10.0	1.9	4.6	2.38
1150	- - -	- - -	Melted	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 15: Bloomsburg Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR5/6 Grayish reddish orange	3	5.0	12.8	24.6	1.91
1050	2.5YR4/6 Strong brown	6	5.0	10.5	20.4	1.93
1100	2.5YR4/4 Moderate reddish brown	6	5.0	9.1	17.4	1.93
1150	- - -	- - -	Melted	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 16: Rose Hill Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	3	2.5	12.0	24.2	2.01
1050	2.5YR4/8 Strong brown	6	5.0	7.0	15.4	2.20
1100	2.5YR4/6 Strong brown	7	7.5	4.1	9.6	2.25
1150	2.5YR3/4 Moderate reddish brown	8	7.5	2.8	6.3	2.31
1200	- - -	- - -	Melted	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 17: Rose Hill Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	3	5.0	10.9	24.1	2.17
1050	2.5YR4/6 Strong brown	6	7.5	9.3	20.2	2.22
1100	2.5YR4/4 Moderate reddish brown	7	7.5	3.3	7.6	2.31
1150	- - -	- - -	Melted	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 18: Rose Hill Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	3	5.0	9.8	21.1	2.15
1050	2.5YR4/8 Strong brown	6	7.5	6.0	13.9	2.27
1100	2.5YR4/4 Moderate reddish brown	7	7.5	4.4	10.1	2.31
1150	- - -	- - -	Melted	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 19: Rose Hill Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	3	2.5	10.4	21.8	2.09
1050	2.5YR4/6 Strong brown	6	7.5	6.3	14.1	2.25
1100	2.5YR4/4 Moderate reddish brown	7	7.5	4.3	9.7	2.26
1150	– – –	– – –	Melted	– – –	– – –	– – –
1200	– – –	– – –	– – –	– – –	– – –	– – –
1250	– – –	– – –	– – –	– – –	– – –	– – –

Sample 20: Rose Hill Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	3	2.5	10.4	21.9	2.11
1050	2.5YR4/8 Strong brown	7	7.5	6.1	14.0	2.30
1100	2.5YR4/4 Moderate reddish brown	7	7.5	3.5	8.1	2.31
1150	– – –	– – –	Melted	– – –	– – –	– – –
1200	– – –	– – –	– – –	– – –	– – –	– – –
1250	– – –	– – –	– – –	– – –	– – –	– – –

Sample 21: Rose Hill Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	3	5.0	10.9	22.3	2.04
1050	2.5YR4/6 Strong brown	6	7.5	6.1	13.6	2.12
1100	2.5YR4/4 Moderate reddish brown	7	7.5	4.2	9.4	2.23
1150	2.5YR3/2 Grayish reddish brown	7	7.5	2.1	4.3	2.23
1200	– – –	– – –	Melted	– – –	– – –	– – –
1250	– – –	– – –	– – –	– – –	– – –	– – –

Sample 22: Rose Hill Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	3	5.0	9.8	20.3	2.08
1050	2.5YR4/6 Strong brown	6	7.5	5.1	11.7	2.27
1100	2.5YR4/4 Moderate reddish brown	7	7.5	2.5	5.7	2.28
1150	- - -	- - -	Melted	- - -	- - -	- - -
1200	- - -	- - -	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 23: Rose Hill Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	4	5.0	11.0	22.8	2.07
1050	2.5YR4/8 Strong brown	6	10.0	6.4	14.4	2.26
1100	2.5YR4/4 Moderate reddish brown	7	10.0	3.8	8.8	2.32
1150	2.5YR3/4 Moderate reddish brown	8	10.0	2.4	5.6	2.34
1200	- - -	- - -	Melted	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

Sample 24: Rose Hill Formation

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR6/8 Moderate orange	3	2.5	11.5	23.3	2.03
1050	2.5YR4/8 Strong brown	6	7.5	6.6	14.8	2.25
1100	2.5YR4/6 Strong brown	7	7.5	4.1	9.6	2.33
1150	2.5YR3/4 Moderate reddish brown	7	10.0	2.6	6.0	2.34
1200	- - -	- - -	Melted	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -	- - -	- - -

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Sample 25: Old Port Formation, shale

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR8/2 Pale yellowish pink to pale grayish pink	3	5.0	20.7	36.1	1.75
1050	2.5YR8/2 Pale yellowish pink to pale grayish pink	3	5.0	18.0	32.4	1.79
1100	10R5/4 Light reddish brown	6	10.0	5.0	11.3	2.27
1150	10R4/4 Moderate reddish brown	6	12.5	0.8	2.0	2.28
1200	10R4/2 Grayish reddish brown	7	15.0	0.8	2.0	2.43
1250	– – –	– – –	Melted	– – –	– – –	– – –

Sample 26: Old Port Formation, clay

Temp. °C	Munsell color	Moh's hard.	% Total shk.	% Abs.	% App. por.	Bulk dens. gm/cc
1000	2.5YR5/8 Light brown	3	2.5	12.3	27.0	2.20
1050	2.5YR5/8 Light brown	3	5.0	11.3	25.0	2.21
1100	10R5/6 Grayish reddish orange	4	5.0	7.9	18.8	2.38
1150	10R4/6 Moderate reddish brown	4	5.0	6.8	16.3	2.41
1200	10R4/4 Moderate reddish brown	4	5.0	5.8	14.1	2.44
1250	– – –	– – –	Melted	– – –	– – –	– – –

APPENDIX 2

BLOATING TESTS* OF CLAY-SHALE SAMPLES

Sample 6: Mahantango Formation
Crushing characteristics: 3/4-in. angular lumps

Temp. °C	Percent absorption	Bulk density gm/cc	lb/ft³	Remarks
1000	9.0	2.05	127.9	No expansion.
1050	10.7	1.67	104.2	Slight expansion.
1100	11.3	1.22	76.1	Fair pore structure.
1150	7.6	0.63	39.3	Some large pores.
1200	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -

Sample 7: Mahantango Formation
Crushing characteristics: 3/4-in. tabular lumps

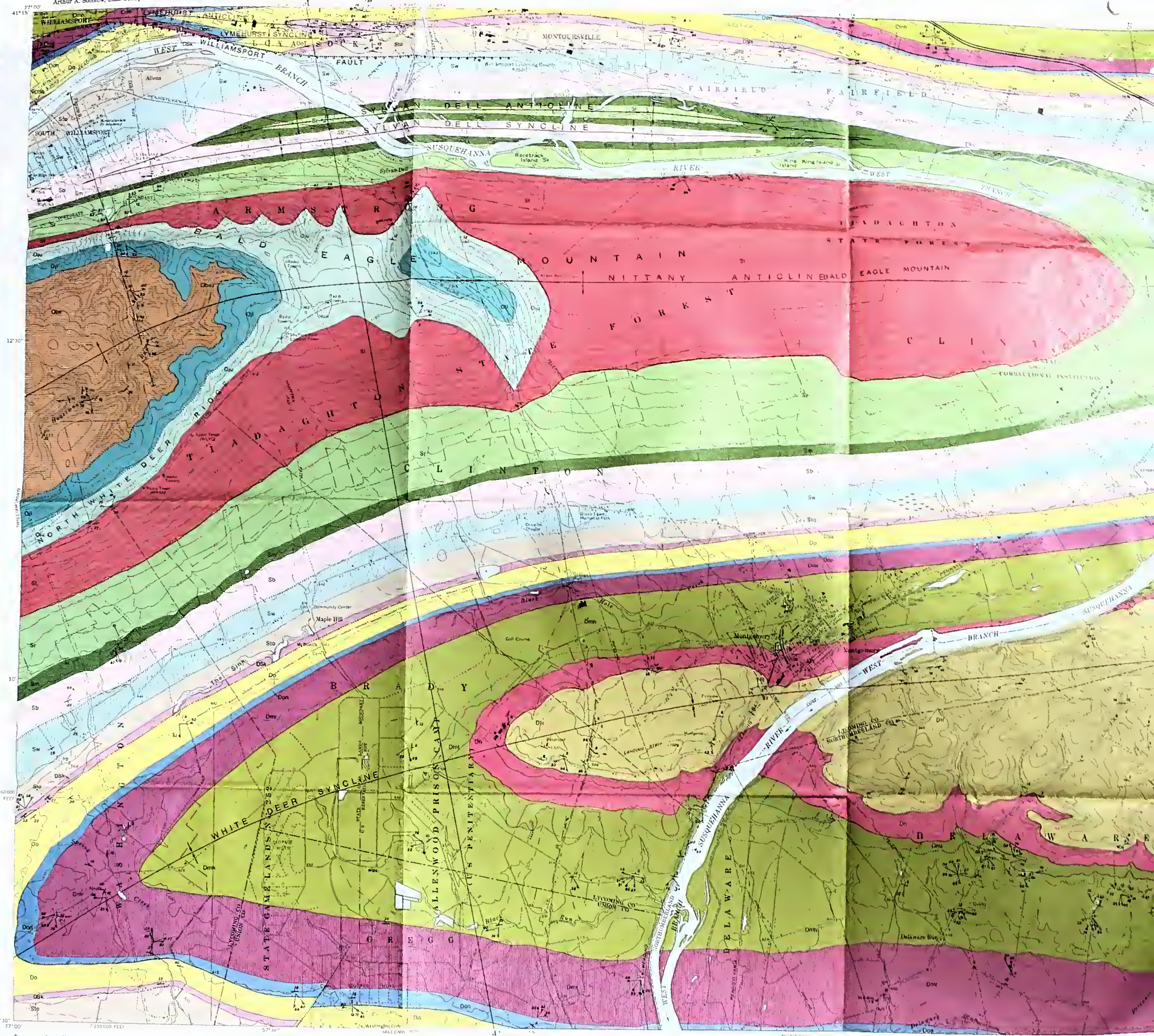
Temp. °C	Percent absorption	Bulk density gm/cc	lb/ft³	Remarks
1000	9.6	1.89	117.9	No expansion.
1050	11.7	1.61	100.5	Slight expansion.
1100	12.3	1.21	75.5	Fair pore structure.
1150	9.9	0.65	40.6	Some large pores.
1200	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -

Sample 8: Mahantango Formation
Crushing characteristics: 3/4-in. tabular lumps

Temp. °C	Percent absorption	Bulk density gm/cc	lb/ft³	Remarks
1000	8.1	2.07	129.2	No expansion.
1050	10.3	1.63	101.7	Slight expansion.
1100	9.8	1.28	79.9	Fair pore structure.
1150	10.1	0.70	43.7	Good pore structure; sticky.
1200	- - -	- - -	- - -	- - -
1250	- - -	- - -	- - -	- - -

*Based on preliminary data obtained from the Tuscaloosa Metallurgy Research Laboratory of the U. S. Bureau of Mines.

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, *State Geologist*



Base map from U.S. Geological Survey Montoursville South, Muncy, and Hughesville 7-1/2 minute quadrangles.

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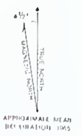
BEDROCK GEOLOGIC MAP OF THE MONTOURSVILLE SOUTH AND MUNCY QUAD LYCOMING, NORTHUMBERLAND, AND MONTOUR

BY

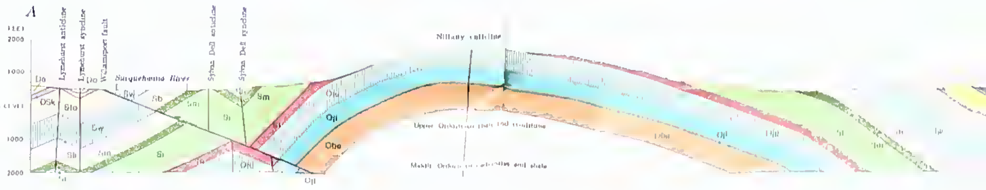
RODGER T. FAILL

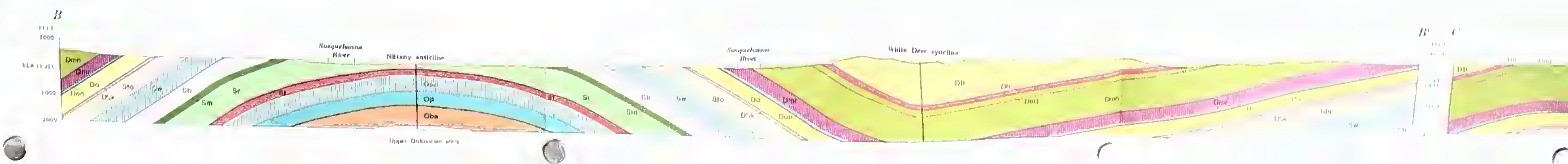
1979



CROSS SECTIONS

(Horizontal scale same as map scale, no vertical exaggeration)





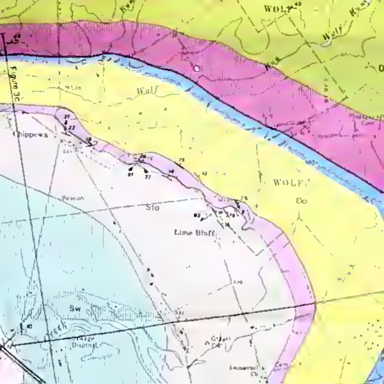

WOLF
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Figure 3C
Wolf
Chippewa
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